

**The Effect of Blade Alignment on Kinetic and Kinematic Characteristics During the Execution of Goaltender-Specific Movement Patterns**

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## Abstract

The goaltender skate traditionally consists of the boot, cowling, and blade runner. The cowling protects the foot and positions the blade on the boot. Innovations in boot design and material properties have deemed the cowling redundant, presenting the opportunity to manipulate skate blade alignment and potentially reveal a performance advantage. The purpose of the study was to investigate the effect of blade alignment on select kinetic and kinematic variables during the execution of two goaltender-specific movement patterns; Butterfly Drop to Recovery, Lateral Butterfly Slide to Recovery. A male goaltender ( $n = 1$ ) with professional hockey experience completed an A-B-A, quasi-experimental design across three days investigating four blade alignment conditions. Blade alignment conditions were defined by the blade holder type and positioning on the boot [alignment neutral cowling (ANC), alignment neutral (AN), alignment lateral (AL), and alignment medial (AM)]. Five trials were executed per blade alignment condition for both movements ( $n=30$  trials per day,  $n=90$  trials overall). All trials were executed in a controlled laboratory environment on synthetic ice (xHockeyProducts™). Kinetic measures included; in-skate peak plantar pressure [PPP(psi)], time to peak plantar pressure [TPP(s)] collected with in-skate LogR™ insoles (Orpyx® Medical Technologies Inc.). Kinematic measures included; butterfly drop velocity [BDV(m/s)], left leg recovery velocity [LLRV(m/s)], right leg recovery velocity [RLRV(m/s)], lateral butterfly slide velocity [LBSV(m/s)], butterfly width [BW(m)] collected with 3D motion capture (Vicon™). Results revealed no significant differences in nineteen of twenty kinetic and kinematic analyses between the two neutral alignment conditions (ANC, AN) defined by different holder types. True Hockey blade holders were retrofit with slots to facilitate the

blade alignments. Results revealed significantly higher Butterfly Drop PPP on the AM compared to AN, and higher Left and Right Leg Recovery PPP on AM compared to AL and AN during the Butterfly Drop to Recovery. Results also revealed significantly higher BDV on AM compared to AL and AN during the Butterfly Drop to Recovery, and higher BDV on AM compared to AN during the Lateral Butterfly Slide to Recovery. Study outcomes provide insight into the contribution of manipulating blade alignment to positively impact the execution of goaltender-specific movement patterns.

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## CHAPTER I: INTRODUCTION

In the sport of ice hockey, the goaltender's equipment is critical to both the athlete's protection and performance. Goaltender-specific equipment was initially introduced in the late 1800's with leg pads and a widened stick (1893) and the first goaltender specific skates manufactured in 1908 (Windsor Hockey Heritage Society, 2017). Significant innovation in design and material properties has resulted in gear that is lighter, larger and more protective, with the intent to potentially contribute to the execution of technique and support the increasing demands of the goaltender position in today's game.

The most common save technique used by goaltenders is the butterfly (Bell et al., 2008). The goaltender assumes a ready stance position, then drops to both knees, while flaring the lower shank of both legs outward involving hip internal rotation equal to the passive limits (Wijdicks et al., 2014), at angles of  $21.2^{\circ} \pm 11.5^{\circ}$  (Whiteside et al., 2015). The effectiveness of the butterfly save technique is primary due to the ability to optimize coverage of the bottom of the net while at the same time allowing the goaltender to remain upright with active arms for coverage of the upper net. From the butterfly position, goaltenders can recover directly to their original ready stance position, move to a new position on their feet, or can slide across the crease while maintaining the butterfly positioning, referred to as the lateral butterfly slide.

Research investigating the contribution of equipment to goaltender specific movement patterns and technique is limited however provides support for further investigation. The contribution of leg pads to the butterfly save technique has been

extensively examined (Frayne et al., 2015; Frayne & Dickey, 2017; Wijdicks et al., 2014). Results revealed significant differences in mean peak butterfly drop velocities measured between 2.82 ( $\pm 0.58$  m/s) and 3.05 ( $\pm 0.64$  m/s) across leg pad channel conditions (Frayne & Dickey, 2017), significant differences in butterfly width measures (0.22 cm) across leg pad channel conditions (Frayne et al., 2015), and significantly greater hip internal rotation with the use of worked-in 27.9 cm wide pads in comparison to new 27.9 cm wide pads (Wijdicks et al., 2014). Result of these studies provide some evidence to suggest that technique can be improved by manipulating goaltender equipment design, fit and function.

The goaltender skate has traditionally consisted of the boot, the cowling, and the blade runner. The boot was originally made from leather and was wrapped by a protective plastic cover, called the cowling. In addition to protecting the foot from the impact forces of pucks, the cowling also served as a rigid interface between the boot and blade, more commonly referred to as a blade holder (U.S. Patent No. 4,453,727, 1982). Consistent with relatively current innovations in the development of the players' skates, the material properties of the goaltenders' skate boot have vastly improved to include synthetic materials, carbon fibers, and resins to improve protection, structure, and durability. These innovations deemed the protective purpose of the cowling somewhat redundant. Furthermore, the cowling restricted the potential to customize blade placement or what is referred to as blade alignment on the boot. It is a common practice within the hockey industry to customize blade alignment on a players skates, to suit the players' anatomical alignment or preference.

As recent as the 2018-19 playing season, goaltenders have adopted blade holders that resemble a players' blade holder; holders that can be aligned and secured to the bottom of the boot. That said, since the industry practice in goaltender skate blade alignment has been limited by the cowling, as it prevented any movement of the blade runner in relationship to the boot, the question arises as to what alignment would be preferential or contribute to the execution of goaltender specific techniques. Therefore, the development of goaltender skates without the cowling has presented an opportunity to investigate the effect of blade alignment on specific techniques to potentially optimize performance.

### **1.1 Purpose**

The purpose of the study was to investigate the effect blade alignment on select kinetic and kinematic variables during the execution of two different goaltender-specific movement patterns. The two goaltender-specific movement patterns analyzed were the Butterfly Drop to Recovery and the Lateral Butterfly Slide to Recovery. Blade alignment conditions were defined by the blade holder (Bauer Vertexx cowling, True Hockey blade holders) and the positioning of the blade holder [alignment neutral cowling (ANC), alignment neutral (AN), alignment lateral (AL), and alignment medial (AM)] in the frontal plane in regard to the centre of the boot. For the purpose of comparing neutral blade alignments, the cowling facilitated neutral alignment (ANC) was compared to the neutral alignment (AN) in the True Hockey blade holders. The True Hockey blade holders were retrofit with a slotted design to facilitate the AN, AL, AM blade alignments for comparison.

## **1.2 Research Questions**

The research aimed to answer the following questions:

1. Was there a significant difference in kinetic [Peak Plantar Pressure (PPP), Time to Peak Plantar Pressure (TPP)] and kinematic [Velocity (V), Butterfly Width (BW)] measures between two neutral alignments (ANC, AN) facilitated by different holder types for two goaltender-specific movement patterns (Butterfly Drop to Recovery, Lateral Butterfly Slide to Recovery)?
2. Was technique across two different goaltender-specific movement patterns (Butterfly Drop to Recovery, Lateral Butterfly Slide to Recovery) consistent/repeatable for each phase of movement when analyzing kinetic [Peak Plantar Pressure (PPP), Time to Peak Plantar Pressure (TPP)] and kinematic [Velocity (V), Butterfly Width (BW)] measures between the baseline conditions in the A-B-A, baseline-intervention-baseline study design?
3. Was there a significant difference in kinetic [Peak Plantar Pressure (PPP), Time to Peak Plantar Pressure (TPP)] and kinematic [Velocity (V), Butterfly Width (BW)] measures across the three blade alignments interventions (AN, AL, AM) for two goaltender-specific movement patterns (Butterfly Drop to Recovery, Lateral Butterfly Slide to Recovery)?

## **1.3 Hypotheses**

The null hypotheses stated:

1. No significant difference in kinetic [Peak Plantar Pressure (PPP), Time to Peak Plantar Pressure (TPP)] and kinematic [Velocity (V), Butterfly Width (W)] measures between two neutral blade alignments (ANC, AN).

$$H_0 = PPP_{ANC} = PPP_{AN}, H_0 = TPP_{ANC} = TPP_{AN}$$

$$H_0 = V_{ANC} = V_{AN}, H_0 = BW_{ANC} = BW_{AN}$$

2. No significant difference in kinetic [Peak Plantar Pressure (PPP), Time to Peak Plantar Pressure (TPP)] and kinematic [Velocity (V), Butterfly Width (W)] across two different goatender-specific movement patterns (Butterfly Drop to Recovery, Lateral Butterfly Slide to Recovery) each phase of movement when analyzing the baseline condition to the baseline condition in the A-B-A, baseline-intervention-baseline study design.

$$H_0 = A_{KINETIC} = A_{KINETIC}$$

$$H_0 = A_{KINEMATIC} = A_{KINEMATIC}$$

3. No significant difference in kinetic [Peak Plantar Pressure (PPP), Time to Peak Plantar Pressure (TPP)] and kinematic [Velocity (V), Butterfly Width (BW)] measures across three blade alignments interventions (AN, AL, AM) for two goatender-specific movement patterns (Butterfly Drop to Recovery, Lateral Butterfly Slide to Recovery)?

$$H_0 = PPP_{AN} = PPP_{AL} = PPP_{AM}, H_0 = TPP_{AN} = TPP_{AL} = TPP_{AM}$$

$$H_0 = V_{AN} = V_{AL} = V_{AM}, H_0 = BW_{AN} = BW_{AL} = BW_{AM}$$



## **CHAPTER II: REVIEW OF LITERATURE**

### **2.1 Evolution of Goaltender Equipment**

The primary purpose of goaltender equipment has been to enhance the athlete's ability, performance, or more specifically, block shots, while providing protection. The performance of the goaltender is defined by save potential; or the athletes ability to prevent the puck from entering their net. Protection of the goaltender is required to prevent injury from high velocity puck impacts, where peak puck velocities from the slap shot have been measured at a mean of 30.6 m/s for college/university hockey players (Wu et al., 2003) to 48.6 m/s at the National Hockey League (NHL) level (NHL, 2019). Protection is facilitated by the protective equipment including: leg pads, catch glove, blocker, chest pad, pants, jock, mask, skates, along with a neck guard, knee guards and other protective gear. The evolution of ice hockey equipment dates back to the early 1800's. The differentiation of positional-specific equipment to support the demands of goaltending-specific play, dates back to the late 1800's. Leg pads and a widened stick were introduced in 1893, the first goaltender-specific skates were manufactured in 1908 (Windsor Hockey Heritage Society, 2017), the catch glove was created as a modified first-base baseball glove (1945) (Hockey Hall of Fame, 2018), a blocker was created from a knee pad sewn to the back of a player's glove (1940s) (Grimm, 2017), and the first mask was worn in the National Hockey League (NHL) (1959). More recently, the size of the equipment has increased to resemble body armour, while the weight has decreased to aid performance.

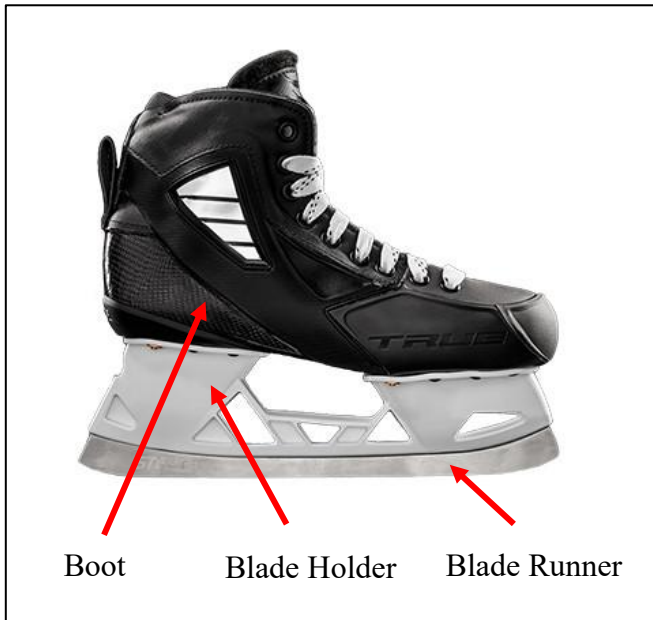
The following section will provide a historical account of goaltender-specific equipment. The development and manufacturing of goaltender equipment has seen significant growth and innovation paralleling the evolution of the game and the demands of the position. The material properties of protective gear have evolved to provide increased protection with decreased weight and improved shock absorption. The leg pads, for example, which were once leather and filled with various animal hairs, are now made from a waterproof synthetic leather filled with light weight, high density foams that not only increase shock absorption but also provide a shape that facilitates goaltender-specific movements. The size of the protective gear has increased parallel to the improvements in material properties, providing goaltenders with not only increased protection, but increased size providing greater net coverage and enabling greater blocking potential. As a result, general and athlete-specific size restrictions were developed to prevent goaltenders from abusing the equipment size and are issued on most individual protective gear pieces.

The purpose of the goaltender stick is to enhance performance and does not directly contribute to protection of the athlete. More specifically, the goaltender stick facilitates the goaltender's ability to make saves and handle the puck. The stick was originally made from wood, similar to player sticks, with the design of the goaltender stick first differentiating from a player's stick (1893) when the bottom half (paddle) was widened on one side, both sides of the paddle were widened in 1915, and by the 1930's, sticks became laminated layers of wood (Windsor Hockey Heritage, 2017).

Improvements in material properties have led to lighter foam core and full composite

sticks that provide greater shock absorption, durability, and ease of use due to the decreased weight.

The primary purpose of the goaltender skate is to facilitate the goaltender's ability to move on the ice while providing protection to the foot. The goaltender skates consist of three main components: the boot, the blade holder, and the skate blade, also referred to as the blade runner. The boot receives the foot, the blade holder is the connection from the boot to the blade runner, and the blade runner is the contact point between the ice and the athlete's foot (See *Figure 1*).



*Figure 1.* Goaltender Skate

Traditionally, goaltender skates were made of soft supple leather providing the athlete with limited protection and support. A toe-guard was added in 1931 (U.S. Patent No. US 1806975A, 1931), and a hard, protective cover, called a cowl, was added in the 1960's. Cowlings offered protection by absorbing and dispersing energy, preventing a direct impact from the puck on the boot. The plastic molded cowl was invented in

1972 as an additional cover that could be attached to a fully constructed skate (U.S. Patent No. 3806145, 1972).

The shape of the boot has not differed vastly with the evolution of material boot properties. However, the emphasis on protection of the foot has increased parallel to the greater intensity of the game, injury frequency, and increases in composite material properties, leading to the first composite skate boot released in 1985 (CA. Patent No. 1192395, 1985), composed of rigid molded and flexible composite plastics, separated into three components. The need for the external protective cowlings has become redundant for current goaltender skates due to increases in boot technology and materials that provide increased protection, along with decreased weight and bulk of the overall boot. These adaptations include a full one-piece carbon fiber and resin composite formed boot (U.S. Patent No. US15087213, 2015), and boots with an outer shell made from synthetic materials and reinforced in any areas that may be susceptible to impact during play, such as the toecap, medial, and lateral sides (U.S. Patent No. 20170080323A1, 2015). Trends of goaltenders adopting cowlingsless skates are evident as the number of active NHL goaltenders using cowlingsless skates has increased from 9.8% in the 2015/2016 season, to 60% in the 2016/2017 season and 70.5% in the 2017-2018 season.

The blades are traditionally affixed to the boot via the blade holder. The first goaltender-specific skate, developed and marketed by Starr Skates (1908), had perpendicular metal platforms riveted to the bottom of the boot (Windsor Hockey Heritage Society, 2017). This skate featured the metal blade and metal platform holders which were to be attached to a leather boot of the goaltender's preference. The design of the cowlings was adapted (U.S. Patent No. 4453727, 1982) to become the blade holder

and also the protective plastic barrier around the boot when it was molded to extend beyond the boot and hold the metal blade runner (1982). The cowling continued as the holder with further evolutions including the introduction of removable and interchangeable blades (U.S. Patent No. 20020190487 A1, 2002). In 2011, the height of the cowling holder increased from the ice and the medial portion of the cowling which makes contact with the ice first on a lateral push was removed (U.S. Patent No. USD641060S1, 2011). This allowed the goaltender to achieve an increased angle between the medial side of the blade and the ice before contact is made with the medial side of the skate, referred to as the attack angle. The current trend of cowlingsless skates (Dunne, 2018) has adopted a blade holder similar to the player skate. Separate plastic holders are now secured to the outsole of the boot that include a blade-detachment mechanism to switch blades in and out of the holders (U.S. Patent No. 29505582, 2015) and a similar plastic holder that is covered by carbon fiber and resin composite extended from the boot downwards (U.S. Patent No. US15087213, 2015).

The skate blade, also referred to as a blade runner, inserts into the blade holder, and is the essential point of contact with the ice. The first goaltender skate (1908) consisted of a steel runner that was longer and flatter than the player's blade runners. The design of the goaltender blade featured the 'Puck Stop' named after its function to prevent a puck squeezing between the sole of the boot and the blade (Windsor Hockey Heritage Society, 2017). The blade runner design was later adapted to insert into the cowling (U.S. Patent No. 4453727, 1982). In 1994, the Overdrive Blade was patented (U.S. Patent No. 5456495, 1994), a metal edge screwed to the medial underside of the cowling by the ball of the foot for an extra edge and to avoid 'slip-out', occurring when

the medial side of the goaltender's skate, typically at the head of the first metatarsal, makes contact with the ice and causes the edge of the runner to lift off of the ice. However, the NHL banned this in 2001.

Evolution of the game of hockey itself has evoked change in material properties, design and functionality. Positional-specific equipment used by goaltenders provides the capabilities to safely block shots from entering their goal, parallel to the increase in speed and accuracy of shots from players. The evolution of the goaltender skate has provided researchers and manufacturers with the ability to manipulate the positioning of the goaltender blade holder and runner in the frontal plane in regard to the boot, referred to as skate blade alignment, a concept not present until recent years.

## **2.2 Biomechanical/Technical Demands of the Goaltender**

The goaltending position is commonly referred to as an individual sport played within a team sport atmosphere, and as such, the biomechanical or technical demands of the goaltender are unique in comparison to those of the players. The primary objective of a goaltender is to stop the puck from entering the net, facilitated by blocking shots, more commonly referred to as saves. This requires high levels of eye-hand coordination, reaction time, quickness, and decision making to compete at an elite level (Bell et al., 2008), combined with highly developed technical skills. Common goaltender-specific techniques include but are not limited to the shuffle, T-Push, butterfly (Bell et al., 2008), and the lateral butterfly slide.

### **2.2.1 Techniques Defined**

Goaltender techniques/skills are initiated from the ready stance position, where the goaltender is in a semi-crouched, upright position, involving hip flexion of  $\sim 70^\circ$ , hip abduction of  $\sim 10^\circ$ , and internal hip rotation between  $\sim 25^\circ$ - $30^\circ$  (Frayne et al., 2015), with the leg pads at an angle between the ice and the athlete, with weight on both skates (Bell et al., 2008). From the ready stance, the goaltender is capable of executing skills involving a mechanism of locomotion or movement to an optimal position in accordance to the shooter and the net to save shots, as well as save techniques when in position. Positioning is facilitated by goaltender-specific movements used within a game. This involves movements in the anterior/posterior directions, lateral directions, and includes combinations of all (Bell et al., 2008). Movement in the anterior/posterior directions involves a sculling skating pattern or a 'c-cut' to move towards the shooter, or to retreat back to the net. Lateral movements involve upright standing techniques including the shuffle for small precise movements and the T-push for explosive movements. When in position, the butterfly technique can be utilized, a save technique characterized by the goaltender dropping to the ice on both knees, while internally rotating the hips so the lower shank is parallel with the ice, removing blade runner contact with the ice, (Ross et al., 2015). The lateral butterfly slide is characterized by a push from the medial edge of the blade runner propelling the goaltender in a lateral direction while in the butterfly positioning.

Time motion analysis (TMA) techniques are used in the sport arena to determine the frequency of specific skills used within a game or event to inform coaches, trainers, and athletes of potential areas of focus when attempting to prioritize and/or refine technique and performance. Bell et al. (2008) conducted a TMA on twenty-four NHL

goaltenders over the span of two seasons. Results identified the most prevalent movements performed in the capacity of a game: vertical movement ( $44\pm 8$ ), (goaltender drops or rises from one or both leg pads), lateral movement ( $41\pm 9$ ), (movement in the frontal plane). Results also identified the most prevalent save techniques led by the butterfly save technique ( $34\pm 6$ ) (Bell et al., 2008). Limitations of this study include not differentiating the specific movement techniques such as the shuffle and T-push skills for the movement directions, and not recording any lateral butterfly movements due to the lower prevalence of the lateral butterfly slide in 2008. This study denotes the large quantity of butterfly movements performed by elite level goaltenders during game play which is hypothesized to have increased in prevalence since 2008.

### **2.2.2 Biomechanical Analysis of Butterfly Techniques**

The butterfly technique was popularized in the 1980s and has gained significant prevalence in today's game. The butterfly consists of several different phases. The butterfly drop is the first phase of the butterfly technique involving the goaltender dropping to the ice on both knees, with internally rotated hip flexion (Frayne et al., 2015) causing the medial aspect of both of the goaltender's pads to lie flat and perpendicular to the ice, to cover the bottom region of the net from the puck. The butterfly technique involves external rotation of the lower legs, in order to flare the left and right shank out to cover the bottom of the net (Bell et al., 2008). Performing the butterfly from the ready stance involves hip extension to keep the upper body erect, and adduction to close gaps between the knees, along with increased internal rotation when the knees move closer to the ice (Frayne et al., 2015). The internal hip rotation involved in the use of the butterfly



technique was equal to passive internal rotation limits of the hip joint discovered during clinical examination (Wijdicks et al., 2014). The biomechanics of the butterfly technique have been described using both kinetic and kinematic analyses. A kinetic analysis of the butterfly technique revealed ground reaction forces from each knee of the goaltender to be roughly 1.45 times the amount of body weight (Wijdicks et al., 2014). Whiteside et al. (2015) approximated peak axial femoral shock of the leg making first contact during the butterfly to be  $8.23 \pm 3.17$  g, significantly higher than during the T-push. Kinematic analyses of the butterfly technique have reported measures of maximal hip internal rotation associated with the butterfly save to be  $21.2 \pm 11.5^\circ$  (Whiteside et al., 2015), and significant differences in mean peak butterfly drop velocities have been measured between  $2.82 \pm 0.58$  m/s and  $3.05 \pm 0.64$  m/s, depending on leg pad channel conditions (Frayne & Dickey, 2017).

From the butterfly drop, the goaltender can perform the butterfly recovery phase involving the goaltender recovering directly vertically into the ready stance, one leg at a time or simultaneously. Due to the high speed of the game, goaltenders do not always have time to recover to the ready stance position from the butterfly before moving laterally across the crease and opt to perform the lateral butterfly slide instead. The lateral butterfly slide is a technique used by goaltenders to provide locomotion in the frontal plane, while maintaining butterfly positioning. This allows the goaltender to move laterally across the crease without wasting time or energy in recovering back to the feet. The goaltender lifts one knee up to create a contact point between the medial edge of the blade runner and the ice and pushes, leaving the lead knee and leg on and parallel to the ice surface followed by returning the push knee and leg back to the ice (USA Hockey,

2018b). The goaltender keeps the upper body upright, and brings the knees close together while sliding to cover the gap in between the legs known as the ‘five-hole’. An increase in the prevalence of the butterfly has shown parallel trends of increases in the lateral butterfly slide although analysis of the lateral butterfly slide was omitted in the latest goaltender TMA (Bell et al., 2008).

In summary, the goaltending techniques include distinctive biomechanical characteristics involved with the skills unique to the position of play. The butterfly is the most prevalent save technique used by goaltender (Bell et al., 2008) informing the analysis of the butterfly drop, recovery, and lateral butterfly slide. The ability to potentially improve the performance of the butterfly phases results in the goaltender achieving optimal positioning quicker, increasing the likelihood to stop the puck from entering the net.

### **2.3 Contribution of Equipment to Performance**

The athlete-equipment interaction has been recognized and well defined (Lockwood & Frost, 2009; Pearsall et al., 2000; Stefanyshyn & Wannop, 2015) beyond the fundamental outcomes associated with physiological, mental and technical training. Innovation in equipment, combined with a consideration for the biomechanical effects of the equipment on the execution of sport specific techniques, can improve sport performance and/or protection. Research conducted on equipment in sliding and gliding sports has primarily addressed four topics: (i) material properties, (ii) design, (iii) fit, and (iv) function of the equipment; all of which independently and/or collectively have the potential to contribute to performance.

### **2.3.1 Material Properties**

Improvements in material properties have had significant effects on athletes within gliding sports ranging from improved hockey skate boot and helmet materials (Pearsall et al., 2015) for protection to the effect of different textile patterns and materials in speed skating skin suits on aerodynamics (Chowdhury et al., 2010). Outside of industrial research and specific to hockey skates, McGurk and Lockwood (2015) investigated the material properties of a commercially available blade runner compared to an experimental material steel runner characterized by an increased surface hardness compared to traditional stainless steel hypothesized to improve skating performance. Findings suggested that the experimental material steel runner in combination with the athlete's preferred blade conditions contributed to increased skating speeds (McGurk & Lockwood, 2015). Many of the major evolutions in hockey goaltending equipment such as lighter foams within the pads, and lighter composite materials in the skate boots have been driven by improvements to material properties available, although research specific to material properties of hockey goaltender equipment has been limited to industrial collaborations with hockey equipment companies.

When material technologies have been enhanced, change in design of the equipment is commonly invoked (Jenkins, 2003). The improvements in the material properties involved in the goaltender skate boot provide sufficient protection to the foot rendering the cowling obsolete. These improved material properties have now led to a design change in the goaltender skate which may have implications to improvements in performance.

### **2.3.2 Design**

Design refers to the overall shape and structure of the sporting equipment. The shape and structure of hockey gear is designed in order to provide the athlete with the ability to compete safely. The design of the goaltender skate specifically involves a composition of three main components: the boot, blade holder, and blade runner.

The height of the goaltender boot is shorter than the player skate boot to optimize plantar and dorsiflexion of the ankle, since the position requires increased mobility of the ankle (Humble & Smith, 2010), while excluding the tendon guard found on a player skate. Research investigating effects of hockey skate boot design on performance has been limited to players (forward, defence) and has focused on promoting plantar flexion or dorsiflexion of the ankle (Fortier & Pearsall, 2010; Lockwood et al., 2013; Lockwood et al., 2014; Ngoc, 2012; Pearsall et al., 2012; Robert-Lachaine et al., 2012; Tidman, 2015). Modifying the tendon guard, the protective Achilles heel guard located on the back of the skate boot, provides greater flexibility for the ankle within the skate boot (Fortier & Pearsall, 2010; Ngoc, 2012; Pearsall et al., 2012; Robert-Lachaine et al., 2012; Tidman, 2015). The top eyelets of the skates have also been manipulated (Lockwood et al., 2013; Lockwood et al., 2014; Ngoc, 2012; Robert-Lachaine et al., 2012), along with the tongue (Fortier & Pearsall, 2010; Pearsall et al., 2012) to provide increased flexibility of the ankle. When allowing for greater ankle flexibility, studies found increases in dorsiplantar flexion range of motion (ROM); mean work; power output; and trends toward increased torque (Pearsall et al., 2012; Robert-Lachaine et al., 2012). Increased flexion of the ankle also provided significant differences in center of pressure (COP) patterns (Ngoc, 2012).

The current blade holder design involves a separate plastic piece that holds the blade runner and is riveted to the bottom of the boot or a refined cowling. Industrial collaborative research specific to goaltending equipment skate design has led to the major redesign of the blade holder to exclude the traditional cowling and become similar to the players. This design was stimulated from the improved synthetic composite skate boot material properties (U.S. Patent No. US15087213, 2015; U.S. Patent No. 20170080323A1, 2015) (2015). The refined cowling, and cowlingsless skates specifically, allow goaltenders to increase the attack angle due to a slimmer shape on the medial aspect of the boot. The current cowlingsless design of the goaltender blade holder also allows for the ability to manipulate blade alignment.

The goaltending performance effects of the increased attack angle and changes to blade alignment have yet to be investigated, although a similar concept was investigated for speed skates, where research has investigated the impact of modifying the position of the pivot point of the klapskate hinge on mechanical changes of the hip, knee, and ankle joint (Houdijk et al., 1999, 2002; Van Horne & Stefanyshyn, 2005). The klapskate is a speed skate that prevents the rigid connection of the blade holder to the boot, and instead provides a hinge to allow the boot to rotate relative to the blade holder, allowing the entire blade to maintain contact with the ice, while the ankle is in plantar flexion (Van Horne & Stefanyshyn, 2005). Houdijk et al. (1999, 2002) and Van Horne and Stefanyshyn (2005) had similar findings when moving the pivot point anteriorly which resulted in significant increases in hip and knee ranges of motion, peak angular velocities, as well as a decrease in angular velocity of the ankle (Houdijk et al., 1999, 2002; Van Horne and Stefanyshyn 2005).

The blade runner is the contact point between the ice and the athlete. The design of the blade runner is defined as having three geometric dimensions: height, length, and width (Broadbent, 1985). The width dimension in current goaltender skates either features a blade that is 3mm wide or 4mm wide, dependent on manufacturer and holder type, and height is consistent with a player's skate runner, however, goaltender runners are significantly longer. The sharpening and customization of the goaltender runners may differ to facilitate goaltender-related skills, and individual athlete preferences.

Customization of the blade runner can include changing the radius of contour (ROC), radius of hollow (ROH), and pitch. The radius of contour (ROC), also referred to as the rocker or profile of the blade, is the profile of the blade in the longitudinal plane. This determines the amount of the skate blade that will be in contact with the ice (Lockwood & Frost, 2009). A smaller the ROC is associated with increased agility, whereas a longer ROC is associated with increased velocity (Lockwood & Frost, 2009). For a goaltender, ROC is not often changed from the stock setting where the ROC is between 28-30 feet (8.53m-9.14m) or greater (Blade-Tek, 2018).

The radius of hollow (ROH) of a skate blade runner is the radius of the groove sharpened between the inside and outside edge of the width of the bottom of the blade and is manipulated by the radius of the grinding wheel used in the sharpening process (Lockwood & Frost, 2009). For a greater focus on speed, a shallow ROH is recommended, whereas a deeper ROH is associated with increased agility (Broadbent, 1983). For a goaltender, a deeper ROH results in greater grip when performing movements and save techniques and is often determined by personal preference and playing style.

The apex or pivot point of the skate blade is referred to as the pitch (Broadbent, 1988; Lockwood & Frost, 2009). The pitch of the blade can be manipulated to alter the position of the apex of the blade, causing a change in the lie (Lockwood & Frost, 2009) and moving an athlete's center of mass (COM) (Broadbent, 1988). For example, moving the apex backwards or increasing height at the back of the blade will shift the skater's COM forward (Broadbent, 1988; Lockwood & Frost, 2009).

Research focusing on performance effects associated with skate sharpening interventions has been limited to player skates and has not involved goaltender skates. Skate sharpening differences have been analyzed by (Cadeau & Lockwood, 2016; Federolf & Redmond, 2010; Lockwood & Frost, 2009; McKenzie & Lockwood, 2012; Morrison et al., 2005; Winchester, 2007). Studies investigating the effect of ROH to performance (Federolf & Redmond, 2010; Morrison et al., 2005) found frictional coefficient differences were increased when the ROH was decreased, and statistically significant differences in agility course times between different ROH (Federolf & Redmond, 2010). Skate blade ROH was found to have no statistical significance on four different physiological variables including heart rate, oxygen consumed, volume of gas expired, and rate of perceived exertion (Morrison et al., 2005). A kinematic analysis determined ROH had a significant effect on stride length and stride rate during acceleration phase and stopping time and distance while completing an anaerobic on-ice skating test (Reed Repeat Skate) (Winchester, 2007). A study by Cadeau and Lockwood (2016) applying recommended ROH, ROC, and pitch to player's runners confirmed that differences in skate blade sharpening characteristics (ROH, ROC, pitch), when combined, may aid in performance. This is dependent on the skating skills of specific player since

there are no universal sharpening characteristics that will benefit every drill or athlete (Cadeau & Lockwood, 2016; Lockwood & Frost, 2009).

Research investigating the structural design of the blade runner includes a study by Federolf and Nigg (2008) investigating the friction of flared ice hockey blades, having a widened base near the bottom of the blade at angles of four, six, and eight degrees with the ice. Results displayed lower coefficients of friction between the blade and the ice with increased blade flare, disproving the hypothesis that thinner blades equal less friction (Federolf & Nigg, 2008).

### **2.3.3 Fit**

The fit of an athlete's equipment is important to increasing comfort in order to potentially optimize performance and protection. Design of different equipment models and brands elicits greater fits for specific athletes compared to others due to independent biomechanical and physiological characteristics. Some skate brands offer athletes a choice between a softer or wider boot, or a tighter, more supportive boot. The fit of the skate boot to a hockey player and goaltender is important as improper fitting skates have the ability to cause severe discomfort including but not limited to blisters, chaffing, protruding bone, and 'lace-bite' which involves painful extensor tenosynovial reactions and venous thromboses of the superficial veins (Minkoff et al., 1994). Goaltender skate boot fit has yet to be analyzed, although Gheorghiu (2005) investigated the fit of ice hockey player skate boots by measuring pressure distribution across the foot and ankle applied by the boot. Subjects were fitted with their correct footwear size, as well as a half size larger and smaller. Pressure distribution was measured about the foot/ankle by seven individual piezo-resistive pressure sensors. Testing involved participants assuming a static



standing and sitting posture, along with weight bearing ankle inversion/eversion and plantar/dorsiflexion patterns. Results displayed significant shifts in pressure distribution about the foot/ankle and the skate boot where sizing up one-half size resulted in decreased pressure about the foot/ankle, while downsizing one-half size increased pressure. A benchmark of 34.2KPa for measured overall pressure was discovered for the proper fit of a hockey player skate. These results have implications to reduce discomfort during play and may have effects on performance and injury prevention (Gheorghiu, 2005). Due to the similarities between player and goaltender skate boots, the results of this study have the potential to be applied to properly fitting the goaltender skate to the athlete.

#### **2.3.4 Function**

In order to optimize the function of equipment, a consideration is needed for the biomechanics of the athlete combined with enhancements to the material properties, design, and fit. As previously stated, the function of goaltender equipment is to provide the athlete with the ability to move with minimized obstruction and enhance goaltending-specific movements and save techniques, while providing sufficient net coverage capabilities, all while protecting the athlete. The three components of the goaltender skate serve vastly different functions. The function of the boot is to protect and provide support to the foot. The function of the blade runner is to be the contact point with the goaltender and the ice, allowing the goaltender to skate and grip the ice to perform necessary movements. The blade holder functions as the attachment point between the boot and the blade runner.

Research investigating functional differences specific to goaltender equipment have been limited to a focus on biomechanical changes of the butterfly associated with different leg pad interventions (Frayne et al. 2015; Frayne & Dickey 2017; Wijdicks et al. 2014). Wijdicks et al. (2014) sought to determine any biomechanical changes in the hips of goaltenders in the butterfly position from a mandated change in goaltender pad width using ten participants with three different pad conditions: their current worked-in 27.9cm pads; a new pair of 27.9cm pads; and a new pair of 30.5cm pads. No statistically significant differences were found in ground reaction forces (GRF), hip kinematics, or drop time (measured from ready stance until goaltender achieves butterfly positioning) between the new 30.5cm wide pads and the new 27.9cm wide pads, suggesting no statistically significant effect on hip biomechanics between the different leg pad widths. However, goaltenders were found to have significantly greater hip internal rotation with the use of worked-in 27.9cm pads ( $20.1 \pm 4.8^\circ$ ) in comparison to new 27.9cm pads ( $17.5 \pm 4.8^\circ$ ) (Wijdicks et al., 2014).

A biomechanical analysis of ice hockey goaltenders conducted by Frayne and Dickey (2017) investigated leg channel designs of goaltender leg pads through four different leg channels by quantifying the kinematics of goaltenders' lower body. Twelve junior hockey goaltenders performed the butterfly save technique with recovery back to the 'ready stance' five times for the four different goaltender pad fit conditions in a repeated measures study on a sheet of synthetic ice (Frayne & Dickey, 2017). Results revealed a significant difference between the different pad channel designs in the transverse plane alone as the stiff-wide leg pad had nearly ten degrees of added rotation in the transverse plane compared to the other three conditions (Frayne & Dickey, 2017).

Results also determined significant differences in mean peak butterfly drop velocities across the different leg channel conditions as follows: flex-tight 3.05 ( $\pm 0.64$  m/s), flex-wide 3.0 ( $\pm 0.59$  m/s), stiff-wide 2.98 ( $\pm 0.51$  m/s), control pad condition 2.82 ( $\pm 0.58$  m/s) (Frayne & Dickey, 2017). These results suggest manipulations to the goaltender leg pad can influence the function of the equipment- specifically increases in butterfly drop performance.

In the sport of ice hockey, skate related research has been driven primarily by industrial collaborations with skate boot manufacturers. A gap exists in hockey skate research regarding the performance effect of skate boot/holder/runner interventions for goaltenders, and blade alignment specifically. Skate blade alignment is the manipulation between the positioning of the holder and blade runner relative to the base of the boot, an aftermarket adjustment of moving the skate holder medially or laterally in accordance to the boot. The holder component of a skate is riveted into the boot and can be manipulated by moving the holder and re-riveting it into place for the proper fit, with the original rivet holes filled in order to prevent moisture entering the skate boot (Childs, 2014).

Standard blade position refers to the blade being aligned longitudinally from the second metatarsal head and second digit, to the center of the heel, allowing for stability within the sagittal plane, meanwhile shifting the blade medially from the standard blade positioning to account for those with a medially deviated subtalar joint, and laterally for an inverted foot improving the contact of the blade with the ice (Humble, 2003). An individual with a foot that is overpronated or oversupinated forces the need to generate muscular strategies in order to maintain a base of support for stability (Cote et al., 2005), which may be corrected by adjusting blade alignment.

Before cowlingsless skates were introduced (2015), the blade inserted into the pre-molded plastic cowlings, and did not allow for movement of the boot or blade runner in accordance to the cowlings, limiting changes in blade alignment. That said, the evolution of the cowlingsless goaltender skate (2015) with a separate blade holder allows for movement of the blade in accordance to the boot has invited the opportunity to investigate optimal alignment and the interaction between skate blade alignment and performance.

#### **2.4 Instrumentation Used in Analysis of Goaltender Biomechanics**

Biomechanical research focused on equipment manipulation effects to goaltending performance have been executed exclusively in lab settings (Frayne et al., 2015; Frayne & Dickey, 2017; Widjicks et al., 2014). In-lab settings allow researchers to simulate ice when analyzing hockey biomechanics by utilizing synthetic ice while facilitating for ease of kinetic pressure measurement with force plates or plantar pressure insoles, along with kinematic three-dimensional motion capture.

Synthetic ice has been used to imitate real ice when analyzing goaltender biomechanics (Frayne et al., 2015; Frayne & Dickey, 2017; Wijdicks et al., 2014) commonly with the use of a layer of lubricant and custom fabric leg pad covers to reduce the coefficient of friction between the pad and the ice. Synthetic ice ( $\mu = 0.27$ ) was compared to real ice ( $\mu = 0.003$ ) for analysis of maximal effort skating mechanics by Stidwell et al. (2010). Findings included similar total force, peak forces, joint angles, contact time, and impulse over time for both surfaces suggesting synthetic ice is suitable when analyzing biomechanics of hockey players.

A common method of measuring selected kinetic variables for ice hockey biomechanics analyses is with the use of portable plantar pressure measurement systems (Dewan et al., 2004; Ngoc, 2012; Pearsall et al., 2012; Trumper et al., 2006). Common limitations found due to plantar pressure measuring instrumentation involved in analysis of hockey biomechanics include a limited number of sensors limiting measurement of pressure mapping (Ngoc, 2012), along with exclusion of areas of the foot in analysis (Trumper et al., 2006). Hamilton et al. (2017) investigated the usefulness of the in-skate plantar pressure insoles LogR™ (Orpyx® Medical Technologies Inc.), a commercial portable plantar pressure system involving eight pressure sensors, in detecting biomechanical differences associated with player skate blade modifications. Comparisons of in-skate pressure distribution and skating times for different skating starts across three different pitch settings were completed. Results revealed statistically significant differences in peak plantar pressure between some pitch conditions as well as statistically significant differences in time to peak plantar pressure for a single subject using a forward start, and a significant negative correlation between trial time and peak plantar pressure. These results suggest that the LogR™ (Orpyx® Medical Technologies Inc.) insoles were capable of detecting differences in plantar pressure patterns from subtle changes in skate blade conditions.

In order to measure and analyze selected kinematic variables, three-dimensional motion capture records movements of the human body by relying on markers attached to body segments. A three-dimensional motion capture marker set specific to goaltenders while wearing equipment was developed and verified by Frayne et al. (2015). The marker set was verified against a verified calibrated anatomical systems technique (CAST)

marker set (Cappozzo et al., 1995) for hip joint kinematics for internal-external rotation, flexion-extension, and abduction-adduction. When quantifying hip kinematics for the butterfly save and recovery technique the marker set was found valid and reliable while also decreasing marker interference caused by the goaltender equipment (Frayne et al. 2015). The marker set was used on the left side of the body as Wijdicks et al. (2014) determined that goaltender leg dominance had no effect on butterfly biomechanics.

The marker set included markers on the left side of the body including four markers located on the pelvis, one marker on the greater trochanter, two rigid clusters on the lateral thigh and posterior shank (elevated five cm off of the shank), with an equipment marker set including markers on the glove/blocker, with four rigid bodies on the goaltender's leg pads. The goaltender specific marker set was again implemented by Frayne and Dickey (2017) to quantify leg pad channel effects on lower body kinematics when completing the butterfly save technique.

## CHAPTER III: METHODOLOGY

### 3.1 Subjects

A male (n=1) goaltender with professional hockey experience was recruited to participate. Eligibility criteria included currently playing, injury free and self-identified that the butterfly technique was their preferred save technique. Subject demographics including age (birth year), height (cm), weight (kg) and equipment characteristics were collected and detailed in *Table 1* and *Table 2*.

Table 1

<i>Subject Characteristics</i>	
	Subject
Birthdate	1992
Height (cm)	193
Weight (kg)	79

Table 2

<i>Subject's Skate Characteristics</i>	
	Subject
Boot Type	True Pro Custom
Blade Type	Step Steel (4mm)
Holder Type	True & Bauer Cowling

Ethical clearance was obtained from the Brock University Research Ethics Board (File #18-096) prior to the beginning of the study.

### 3.2 Study Design

An A-B-A, quasi-experimental design scheduled across three days was conducted on four blade alignment conditions. Collection days were scheduled exactly one week apart with a different blade alignment intervention (B) on each day. The research was conducted in a controlled laboratory environment with all trials executed on synthetic ice

(xHockeyProducts™). Five trials were executed on baseline-intervention-baseline blade alignments for the Butterfly Drop to Recovery and the Lateral Butterfly Slide to Recovery (n=30 trials per day, n=90 trials overall).

### **3.3 Alignment Conditions**

Blade alignment conditions were defined by the blade holder (Bauer Vertexx cowling, True Hockey blade holders) and the positioning of the blade holder [alignment neutral cowling (ANC), alignment neutral (AN), alignment lateral (AL), and alignment medial (AM)] in the frontal plane in regard to the centre of the boot. For the purpose of comparing holder types, the alignment neutral cowling (ANC) dictated by a Bauer cowling was compared to the alignment neutral (AN) dictated by the True Hockey blade holders. The True Hockey blade holders were retrofit with a slotted design to facilitate the AN, AL, AM blade alignments for comparison. The alignment neutral cowling (ANC) was considered the baseline condition for the first day of data collection and required the participant to wear a True Pro Custom skate boot with a Bauer Vertexx cowling and Step Steel blade runner (See *Figure 2*), where the cowling dictated a neutral blade alignment.





*Figure 1.* True Skate with Bauer Vertexx Cowling

The AN, AL, and AM blade alignments required the participant to wear a True Pro Custom 2-Piece skate boot (See *Figure 3*) without a cowling, a True blade holder and Step Steel blade runner.



*Figure 2.* True Skate with True Holders

Three blade holders were modified with a rotary tool to facilitate the three different alignment interventions; AN, AL, and AM (See *Figure 4*) as described below:

1. blade alignment neutral (AN): centered blade alignment - alignment intervention on the first day of collection, and the baseline condition for the remaining two days.
2. blade alignment lateral (AL): blade was shifted 0.55cm laterally from the centre of the boot - alignment intervention on day two of collection.
3. blade alignment medial (AM): blade was shifted 0.55cm medially from the centre of the boot - alignment intervention on day three of collection.



*Figure 4.* Blade Alignment Conditions. Alignment conditions pictured left to right; Alignment Neutral Cowling (ANC), Alignment Neutral (AN), Alignment Lateral (AL), Alignment Medial (AM)

The modified blade holders shifted the anterior and posterior ends of the blade runner equal distance (0.55cm) from neutral. The AM and AL displacements were based on the maximal achievable displacement facilitated by the True blade holders.

The order of testing was as follows:

Day 1. ANC-AN-ANC

Day 2. AN-AL-AN

Day 3. AN-AM-AN

### **3.4 Experimental Protocol**

A brief familiarization period was consistent across each blade alignment, including a five-minute warm-up consisting of self-selected patterns of goaltending specific drills including shuffle, T-push, butterfly, lateral butterfly slides, and recoveries. All blade

runner height, width, and sharpening characteristics were held consistent. Radius of contour (ROC) was 30', Radius of Hollow (ROH) was sharpened to 5/8", and Pitch (P) was neutral.

The participant was required to wear their own goal equipment including glove, blocker, stick, knee pads, leg pads, and form-fitting clothes (pants and shirt). Goaltender leg pads interact with the skate and influence the biomechanics of the goaltender specific butterfly technique and therefore, the investigation of blade alignment on the performance of these techniques needed to include the use of leg pads. Hockey pants were not worn to eliminate the chance of the pants interfering with the three-dimensional marker set used for kinematic analysis.

After the completion of each trial, the participant rated their own technique as acceptable or non-acceptable. The technical expertise and experience of the participant ensured knowledge of a well-executed goaltender specific movement pattern. The participant repeated trials until five acceptable trials were achieved. A cut-off of five unacceptable trials per collection day was implemented. Following each set of trials (5), the participant self-reported a rating of perceived exertion (RPE) based on the Borg scale of 6-20 (Borg, 1998).

A work to rest ratio of 1:10 was established between trials. This is consistent with the W:R ratios prescribed for the anaerobic energy demand of a maximal effort. The amount of rest between conditions was approximately ten minutes in order to provide the researcher time to adjust the blade alignment.

A detailed technical description of the goaltender-specific movement patterns used for the purpose of analysis includes:

1. **Butterfly Drop to Recovery Trials:** The participant began in the ready stance on synthetic ice. At maximal effort they performed: phase one; butterfly drop (to both knees), phase two; left leg butterfly recovery, phase three; right leg butterfly recovery, where the movement concluded back in the ready stance.
2. **Lateral Butterfly Slide to Recovery Trials:** The participant began in the ready stance on synthetic ice. At maximal effort they performed: phase one; butterfly drop (to both knees), phase two; lateral butterfly slide (to their right via a push with the medial edge of the left blade runner), phase three; right leg butterfly recovery, phase four; left leg butterfly recovery, where the movement concluded back in the ready stance.

### **3.5 Data Collection**

Both kinetic and kinematic data were collected simultaneously across all trials for the purpose of comparative analyses.

#### **3.5.1 Kinetic Data Collection**

Kinetic data was collected using a novel wireless portable plantar pressure distribution insole system (LogR<sup>TM</sup>, Orpyx® Medical Technologies Inc.) (See *Figure 5*) connected via Bluetooth to an iOS device.



*Figure 5.* Orpyx LogR™ Plantar Pressure Insoles

Data was pushed from the iOS device to the Orpyx LogR™ Cloud. The insoles were customized to fit the participant's skate boots. Each insole consists of eight plantar pressure sensors sampling at 100 Hz. The eight large sensors positioned at the bony prominences of the foot limit reliable COP measures due to the lack of sensors, and the inability to extrapolate in-sensor data of individual sensors. Insoles were inserted into the skates, and the skates were tied similar to how the athlete would tie their skates during game conditions. The insole data logger was tethered through the laces of the boot and secured to anterior aspect of the skate boot (See *Figure 6*).





*Figure 6. Orpyx LogR™ Plantar Pressure Insoles Installed in Skates*

Prior to each blade alignment condition, the insoles were zeroed in an unweighted position. The subject held their legs (with pads strapped on) and feet in the air in order to tare the pressure within the skate. Secondly, standing plantar pressure measures were obtained for five seconds in order to determine body weight.

### **3.5.2 Kinematic Data Collection**

Kinematic data was collected using a three-dimensional Vicon motion capture system and Nexus 2.8.1 Vicon Nexus Clinical and Biomechanics software (Vicon™, Oxford, UK). Ten cameras sampling at 330 Hz were set up. The marker set implemented was an adapted version from Frayne et al. (2015) that was validated against a verified calibrated anatomical systems technique (CAST) marker set for hip joint kinematics for internal-external rotation, flexion-extension, and abduction-adduction (Cappozzo et al.,

1995). When quantifying hip kinematics for the butterfly save technique the marker set was found valid and reliable while also decreasing interference due to goaltender equipment (Frayne et al. 2015). For the purpose of this study, markers on the gloves and posterior shank were omitted from the marker set. The marker set used (See *Figure 7* and *Figure 8*) included markers on the body and the leg pads including:

**Body:**

- 1- Left anterior superior iliac spine
- 1- Right anterior superior iliac spine
- 1- Left posterior superior iliac spine
- 1- Right posterior superior iliac spine
- 4- Left lateral thigh - rigid cluster
- 1- Left heel
- 1- Right heel

**Leg Pads:**

- 4- Left upper thigh region - rigid cluster
- 4- Left knee roll region - rigid cluster
- 4- Left shank region - rigid cluster
- 4- Left toe region - rigid cluster
- 4- Right upper thigh region - rigid cluster
- 4- Right knee roll region - rigid cluster
- 4- Right shank region - rigid cluster
- 4- Right toe region - rigid cluster

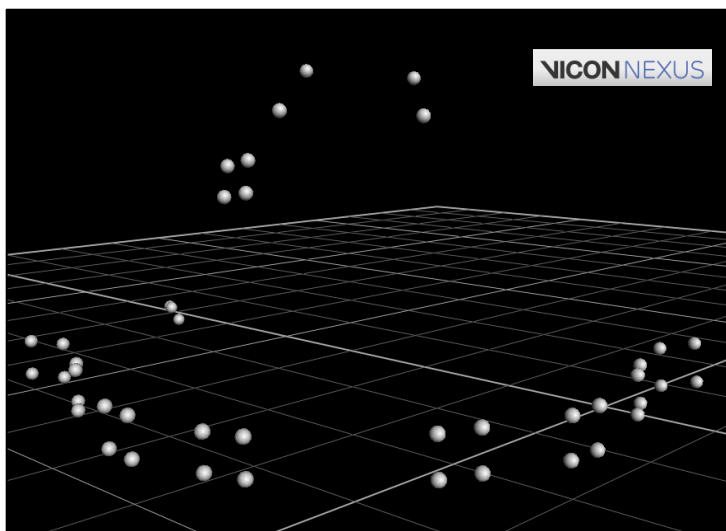
**Total:** 42 markers



*Note.* All rigid clusters on the leg pads were elevated 3cm off of the surface of the pad with foam blocks in order to prevent interference caused by the protusion of the leg pad outer roll blocking the markers from the camera view.



*Figure 7.* Three-Dimensional Vicon Motion Capture Reflective Marker Set



*Figure 8.* Reflective Marker Set in Nexus 2.8.1 Vicon Nexus Clinical and Biomechanics software

The marker set was fastened to the equipment using double-sided tape. Kinematic variables included butterfly drop time (s), butterfly drop displacement (m), left leg butterfly recovery time (s), left leg butterfly recovery displacement (m), right leg butterfly recovery time (s), right leg butterfly recovery displacement (m), lateral butterfly slide time (s), lateral butterfly slide displacement (m), and butterfly width (m).

### **3.6 Data Analyses**

#### **3.6.1 Kinetic Data Analyses**

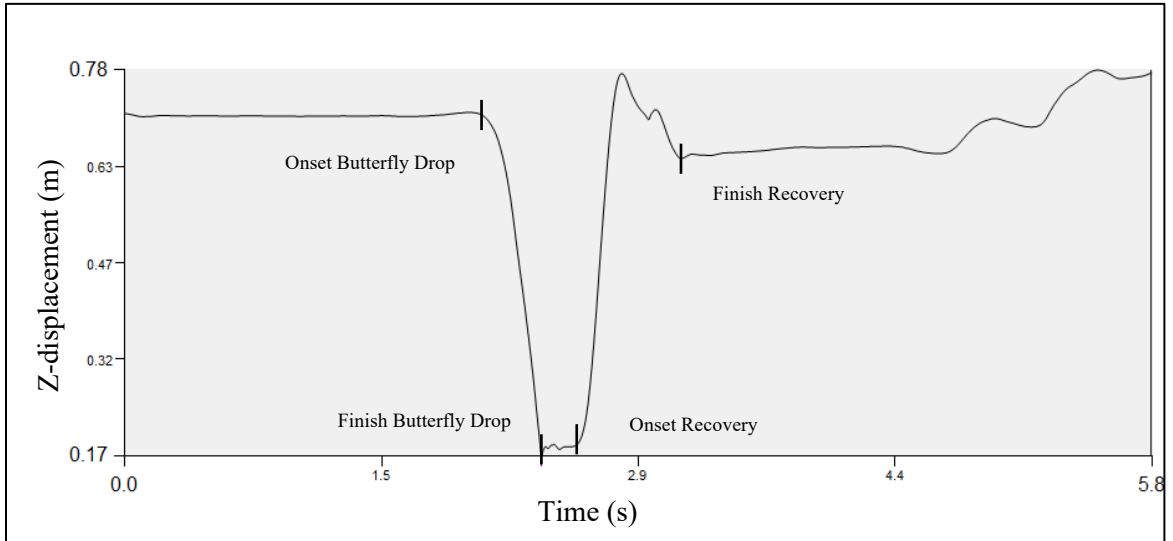
Kinetic data was processed by hand due to the limited analyses tools currently available within Orpyx LogR™ Cloud software. Outcome measures included:

(i) in-skate peak plantar pressure [PPP(psi)]: defined by the peak plantar pressure occurring during the goaltender-specific movement pattern being performed, (ii) time to peak plantar pressure [TPP(s)]: defined by the time between the onset of each movement phase and the peak plantar pressure. For the butterfly drop to recovery movement, PPP and TPP were collected during the butterfly drop phase for the sum of both left and right feet total to account for the bilateral movement and at the left leg butterfly recovery phase and right leg butterfly recovery phase for the individual corresponding foot due to the unilateral nature of each phase. For the lateral butterfly slide to recovery movement, PPP and TPP were collected for the left foot as this is a left leg unilateral movement.

#### **3.6.2 Kinematic Data Analyses**

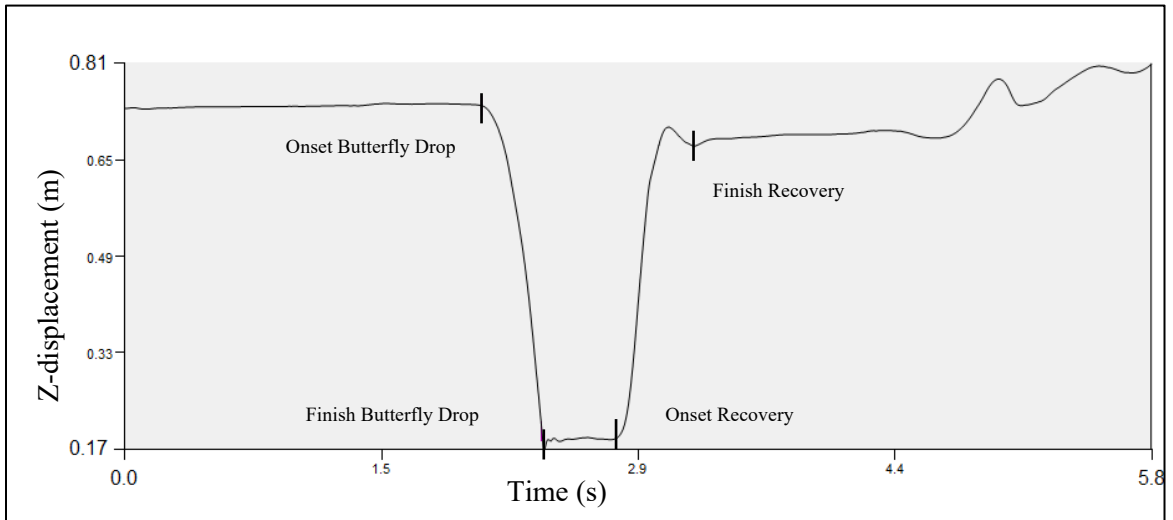
Markers were labeled using the Nexus 2.8.1 Vicon Nexus Clinical and Biomechanics software (Vicon™, Oxford, UK). Kinematic data was then transferred to the Visual3D v6 Professional software (C-Motion Inc., Germantown, MD, USA). Event markers were defined for the phases of the goaltender-specific movement patterns based

upon the top and most lateral marker on the left and right leg upper thigh region rigid cluster and by hand (See *Figures 9a* and *9b* and *Figures 10a* and *10b*).



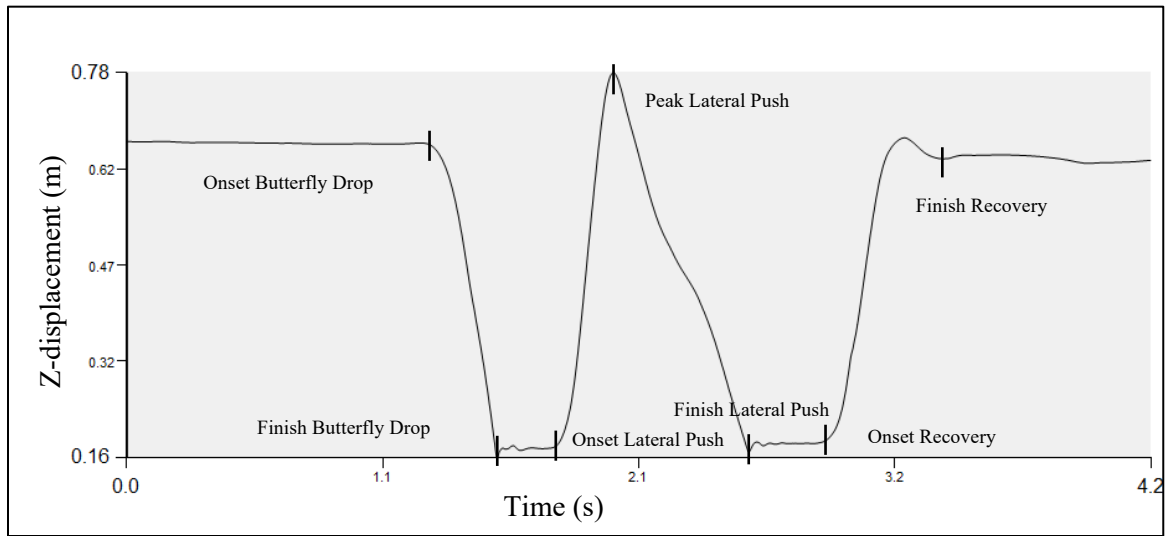
*Figure 9a.* Event Markers For Left Leg During Butterfly Drop to Recovery.

Displacement in z-axis of the upper right marker of the upper thigh cluster on the left leg.



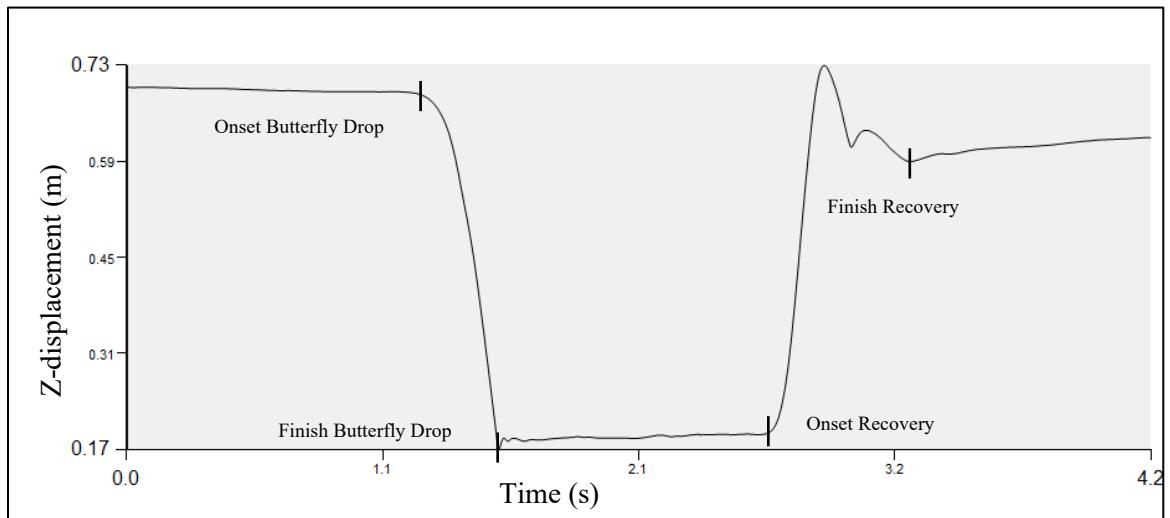
*Figure 9b.* Event Markers For Right Leg During Butterfly Drop to Recovery.

Displacement in z-axis of the upper left marker of the upper thigh cluster on the right leg.



*Figure 10a.* Event Markers For Left Leg During Lateral Butterfly Slide to Recovery.

Displacement in z-axis of the upper right marker of the upper thigh cluster on the left leg.



*Figure 10b.* Event Markers For Right Leg During Lateral Butterfly Slide to Recovery.

Displacement in z-axis of the upper left marker of the upper thigh cluster on the right leg.

Outcome measures included:

(i) Butterfly Drop Velocity [BDV(m/s)] – collected during phase one of the butterfly drop to recovery and lateral butterfly slide to recovery movements. Defined by the average velocity from the onset of movement of the upper right marker of the upper thigh cluster on the left leg from the ready stance in the z-axis until the leg pads are flush with the ice in the butterfly position signaled by the lowest point in the z-axis by the same marker; measured by the vertical distance (m) travelled in the z-axis by the upper right marker of the upper thigh cluster on the left leg pad from the onset butterfly drop to finish butterfly drop event markers divided by the time (s) between these event markers.

(ii) Left Leg Recovery Velocity [LLRV(m/s)]– collected during phase two of the butterfly drop to recovery movement and phase four of the lateral butterfly slide to recovery movement. Defined by the average velocity from the onset of movement of the upper right marker of the upper thigh cluster on the left leg pad in the z-axis from the recovery onset back to the ready stance; measured by the vertical distance (m) covered in the z-axis from the upper right marker of the upper thigh cluster on the left leg pad from the onset recovery to the finish recovery event markers divided by the time (s) between these event markers.

(iii) Right Leg Recovery Velocity [RLRV(m/s)] – collected during phase three of the butterfly drop to recovery movement and phase three of the lateral butterfly slide to recovery movement. Defined by the average velocity from the onset of movement of the upper left marker of the upper thigh cluster on the right leg pad in the z-axis from the recovery onset back to the ready stance; measured by the vertical distance (m) covered in the z-axis from the upper left marker of the upper thigh cluster on the right leg pad from the onset recovery to the finish recovery event markers divided by the time (s) between

these event markers.

(iv) Lateral butterfly slide velocity [LBSV(m/s)] – collected during phase two of the lateral slide to recovery movement, defined by the average velocity from the onset of the lateral push until the onset of the right leg butterfly recovery. The onset of the lateral butterfly slide was determined by the initial movement of the upper right marker of the upper thigh cluster on the left leg pad in the z-axis signaling the moment the knee leaves contact with the ice to generate the push. Lateral butterfly slide velocity was defined by the resultant displacement (m) covered (resultant calculated by displacement in both x-axis and y-axis) by the upper left marker of the upper thigh cluster on the right leg pad divided by time (s) between the onset of lateral push from the left leg and onset of recovery of the right leg pad event markers.

(v) Butterfly width [BW(m)] – collected during phase one of the Butterfly Drop to Recovery and Lateral Butterfly Slide movements. Defined by the resultant displacement in the x-axis and y-axis (m) between the lower right marker of the toe marker on the left pad to the lower left marker of the toe marker on the right pad at the butterfly drop finish event marker.

### **3.7 Statistical Analyses**

Data was analyzed using the Statistical Package for the Social Sciences (SPSS) software, version 25.0 (IBM, Chicago, IL). Descriptive statistics, including mean (M) and standard deviation (SD) were calculated for all kinetic variables (PPP, TPP) and kinematic variables (BDV, BW, LLRV, RLRV, LBSV). A series of Repeated Measures

Analysis of Variance (ANOVA)s were conducted in order to address the three research questions:

i) to determine if significant differences existed in the kinetic (PPP, TPP) and kinematic (BDV, BW, LLRV, RLRV, LBSV) measures between the two neutral blade alignments (ANC, AN) facilitated by different holder types, ii) to determine if technique across two different goaltender-specific movement patterns (Butterfly Drop to Recovery, Lateral Butterfly Slide to Recovery) was consistent/repeatable for each phase of movement when analyzing kinetic and kinematic measures between the baseline condition to the baseline condition in the A-B-A, baseline-intervention-baseline study design, iii) to determine if significant differences existed in kinetic and kinematic measures across the three alignment interventions (AN, AL, AM).

*Post-hoc* Bonferroni significance tests were conducted to determine where the significant differences existed. An alpha level of  $p \leq 0.05$  was set for all analyses to represent statistical significance.

## **CHAPTER IV: RESULTS**

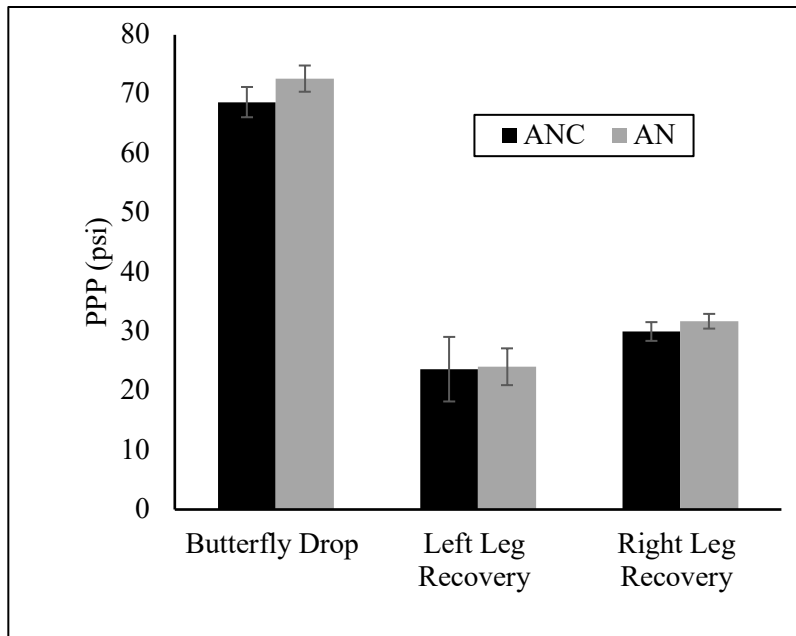
### **4.1 Alignment Neutral Cowling vs. Alignment Neutral**

The following section provides the kinetic and kinematic results of the ANC and AN blade alignment analyses to address research question 1: Was there a significant difference in kinetic [Peak Plantar Pressure (PPP), Time to Peak Plantar Pressure (TPP)] and kinematic [Velocity (V), Butterfly Width (BW)] measures between the two neutral blade alignments (ANC and AN) facilitated by a different holder type for two goaltender-specific movement patterns (Butterfly Drop to Recovery, Lateral Butterfly Slide to Recovery)?

#### **4.1.1 Kinetic Analyses Between ANC and AN Blade Alignments**

Kinetic measures for the Butterfly Drop to Recovery (Mean  $\pm$  SD) across the three phases (Butterfly Drop, Left Leg Recovery, Right Leg Recovery) of the movement are presented in *Figure 11*.

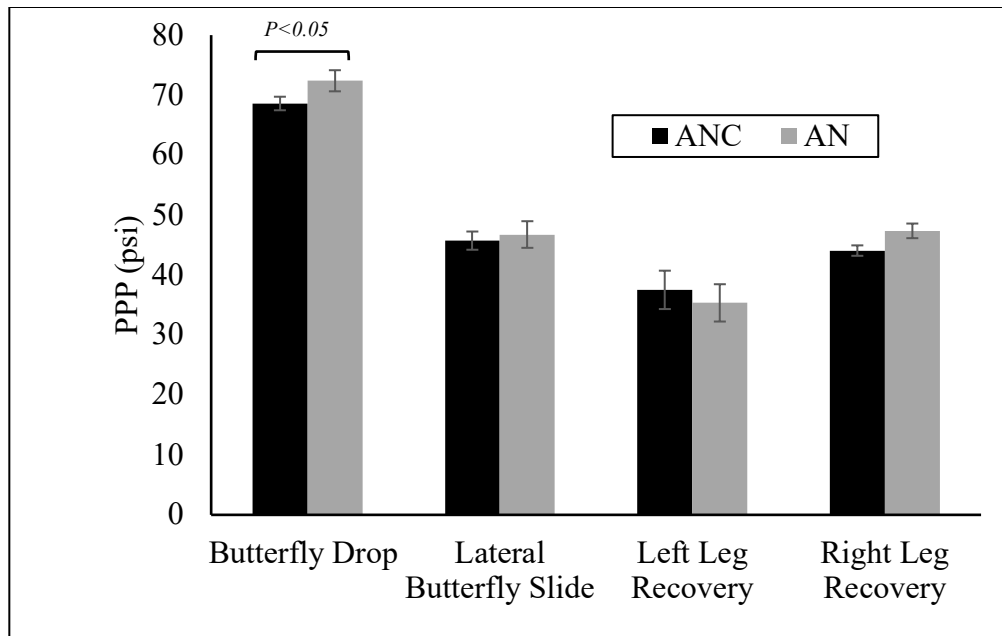




*Figure 11.* Kinetic Results Between ANC-AN Alignments for all Phases of the Butterfly Drop to Recovery. *Note:* Error bars represent between trial standard deviations. TPP measures have been omitted as no significant differences were revealed across all phases.

The series of within-subject Repeated Measures Analysis of Variance (ANOVA)s (n=5) revealed no significant differences in PPP or TPP measures between the ANC and AN blade alignments for the three phases of the Butterfly Drop to Recovery movement.

Kinetic measures for the Lateral Butterfly Slide to Recovery (Mean  $\pm$  SD) across the four phases (Butterfly Drop, Lateral Butterfly Slide, Left Leg Recovery, Right Leg Recovery) of the movement are illustrated in *Figure 12*.

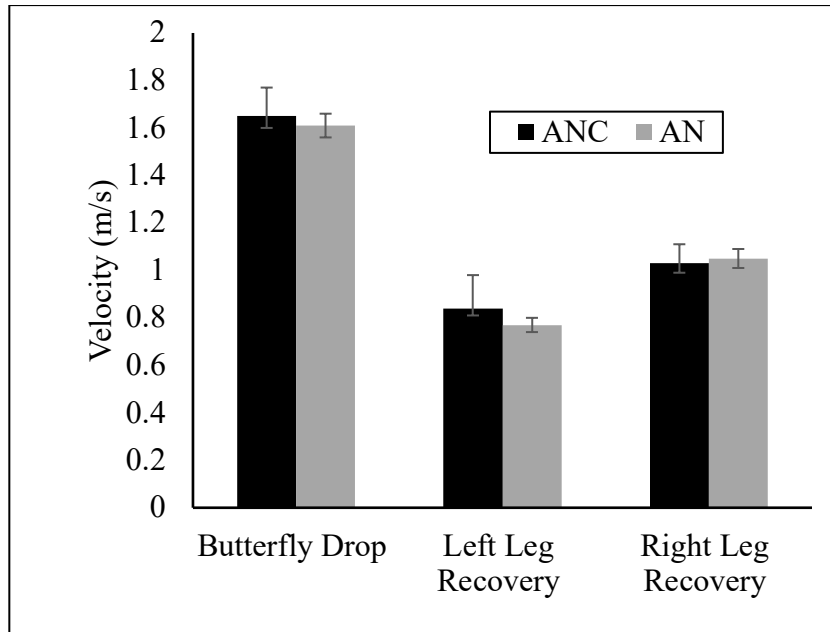


*Figure 12.* Kinetic Results Between ANC-AN Alignments for all Phases of the Lateral Butterfly Slide to Recovery. *Note:* Error bars represent between trial standard deviations. TPP measures have been omitted as no significant differences were revealed across all phases.

The series of within-subject Repeated Measures Analysis of Variance (ANOVA)s ( $n=7$ ) revealed no significant difference between the ANC and AN blade alignments for six of the seven ANOVAs. The only significant difference between the ANC and AN blade alignments was found for the Butterfly Drop PPP,  $F(2,8) = 27.83$ ,  $p = 0.0$ , partial  $\eta^2 = 0.87$ . A pairwise comparison using a Bonferroni post hoc test revealed Butterfly Drop PPP on AN ( $M = 72.39$ ,  $SD = 1.76$ ) was significantly ( $p < 0.01$ ) higher than Butterfly Drop PPP on ANC ( $M = 68.60$ ,  $SD = 1.13$ ). Therefore, a greater amount of pressure (psi) was exerted on the AN alignment compared to the ANC alignment during the Butterfly Drop phase specifically.

#### 4.1.2 Kinematic Analyses Between ANC and AN Blade Alignments

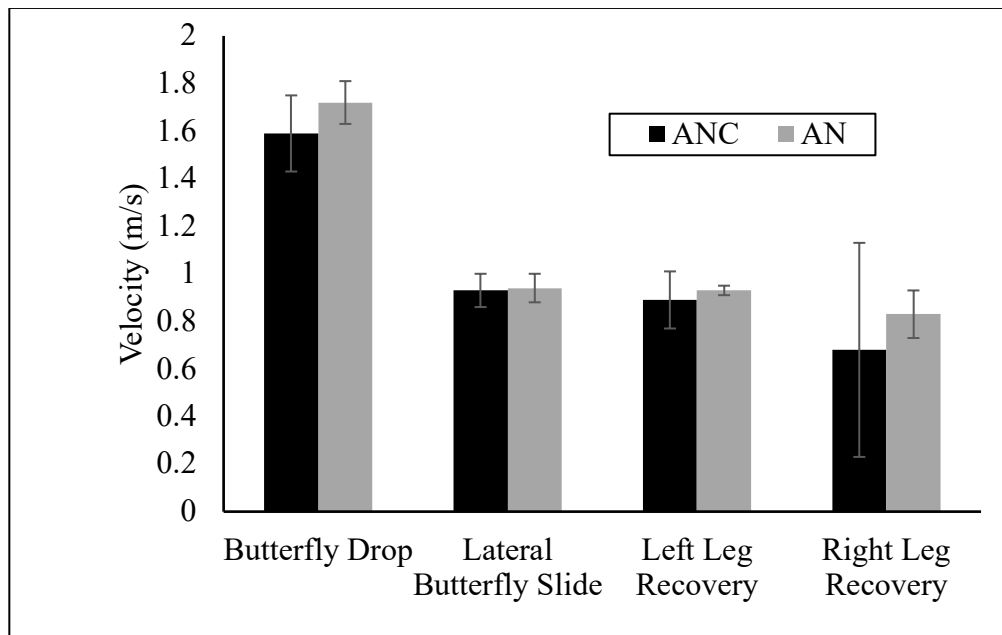
Kinematic measures for the Butterfly Drop to Recovery (Mean  $\pm$  SD) across the three phases (Butterfly Drop, Left Leg Recovery, Right Leg Recovery) of the movement are illustrated in *Figure 13*.



*Figure 13.* Kinematic Results Between ANC-AN Alignments for all Phases of the Butterfly Drop to Recovery. *Note:* Error bars represent between trial standard deviations. BW measures have been omitted as no significant differences were revealed across all phases.

The series of within-subject Repeated Measures Analysis of Variance (ANOVA)s ( $n = 4$ ) revealed no significant differences in Butterfly Drop Velocity (BDV), Butterfly Width (BW), Left Leg Recovery Velocity (LLRV), and Right Leg Recovery Velocity (RLRV) between the ANC and AN blade alignments for the three phases of the Butterfly Drop to Recovery movement.

Kinematic measures for the Lateral Butterfly Slide to Recovery (Mean  $\pm$  SD) across the four phases (Butterfly Drop, Lateral Butterfly Slide, Left Leg Recovery, Right Leg Recovery) of the movement are illustrated in *Figure 14*.



*Figure 14.* Kinematic Results Between ANC-AN Alignments for all Phases of the Lateral Butterfly Slide to Recovery. *Note:* Error bars represent between trial standard deviations. BW measures have been omitted as no significant differences were revealed across all phases.

The series of within-subject Repeated Measures Analysis of Variance (ANOVA)s ( $n = 4$ ) revealed no significant differences in Butterfly Drop Velocity (BDV), Lateral Butterfly Slide Velocity (LBSV), Left Leg Recovery Velocity (LLRV), and Right Leg Recovery Velocity (RLRV) between the ANC and AN blade alignments for the four phases of the Butterfly Drop to Recovery movement.

In summary, a total of twenty within-subject Repeated Measures Analysis of Variance (ANOVA)s were conducted. Nineteen revealed no significant differences between ANC and AN blade alignments in various kinetic and kinematic measures during the two goaltender-specific movement patterns (Butterfly Drop to Recovery, Lateral Butterfly Slide to Recovery, providing the researcher with the confidence to use AN as a dedicated neutral baseline alignment for the remaining data collection.

#### **4.2 Consistency/Repeatability of Trials Between Baselines in A-B-A Design**

The following section provides the kinetic and kinematic results of the two baselines, referred to as ‘A’ components of the A-B-A design (baseline-intervention-baseline) for each blade alignment to address research question 2: Is technique across two different goaltender-specific movement patterns (Butterfly Drop to Recovery, Lateral Butterfly Slide to Recovery) consistent/repeatable for each phase of movement when analyzing kinetic [Peak Plantar Pressure (PPP), Time to Peak Plantar Pressure (TPP)] and kinematic [Velocity (V), Butterfly Width (BW)] measures between the baseline conditions in the A-B-A, baseline-intervention-baseline study design?

##### **4.2.1 Kinetic Analyses for Consistency/Repeatability of Trials Between Baselines**

The series of within-subject Repeated Measures Analysis of Variance (ANOVA)s (n= 18) were conducted to determine if significant differences existed in kinetic measures (PPP, TPP) for the three phases (Butterfly Drop, Left Leg Recovery, Right Leg Recovery) of the Butterfly Drop to Recovery movement. Findings suggested that fourteen

of the eighteen analyses had no significant difference between baselines. Only four of the eighteen analyses revealed significant differences, specifically: Butterfly Drop PPP for ANC-AN-ANC, the second baseline ( $M=72.70$ ,  $SD=1.65$ ) was significantly ( $p<0.03$ ) higher than the first baseline ( $M=68.66$ ,  $SD=2.55$ ); Right Leg Butterfly Recovery PPP for ANC-AN-ANC, the second baseline ( $M=34.72$ ,  $SD=2.13$ ) was significantly ( $p<0.004$ ) higher than the first baseline ( $M=30.00$ ,  $SD=1.58$ ); Left Leg Butterfly Recovery PPP for AN-AL-AN, the second baseline ( $M=28.95$ ,  $SD=4.91$ ) was significantly ( $p<0.009$ ) higher than the first baseline ( $M=13.78$ ,  $SD=1.81$ ); and Right Leg Butterfly Recovery PPP for AN-AM-AN, the second baseline ( $M=40.46$ ,  $SD=0.59$ ) was significantly ( $p<0.003$ ) higher than the first baseline ( $M=33.08$ ,  $SD=1.97$ ).

The series of within-subject Repeated Measures Analysis of Variance (ANOVA)s ( $n=24$ ) were conducted to determine if significant differences existed in kinetic measures (PPP, TPP) for the four phases (Butterfly Drop, Lateral Butterfly Slide, Left Leg Recovery, Right Leg Recovery) of the Lateral Butterfly Slide to Recovery movement. Findings suggested that twenty-one of the twenty-four analyses had no significant difference between baselines. Only three of the twenty-four analyses revealed significant differences, specifically: Butterfly Drop PPP for ANC-AN-ANC, the second baseline ( $M=71.37$ ,  $SD=1.40$ ) was significantly ( $p<0.029$ ) higher than the first baseline ( $M=68.6$ ,  $SD=1.13$ ); Butterfly Drop PPP for AN-AL-AN, the second baseline ( $M=80.45$ ,  $SD=2.05$ ) was significantly ( $p<0.04$ ) higher than the first baseline ( $M=75.4$ ,  $SD=1.26$ ); Left Leg Butterfly Recovery PPP for AN-AM-AN, the first baseline ( $M=39.2$ ,  $SD=1.78$ ) was significantly ( $p<0.007$ ) higher than the second baseline ( $M=35.04$ ,  $SD=2.92$ ).

In summary, of the kinetic measures collected on the two goaltender-specific movement patterns (Butterfly Drop to Recovery, Lateral Butterfly Slide to Recovery) between the first and second baselines in the A-B-A study design (baseline-intervention-baseline), a total of thirty-five of forty-two analyses revealed no significant difference.

#### **4.2.2 Kinematic Analyses for Consistency/Repeatability of Trials Between Baselines**

The series of within-subject Repeated Measures Analysis of Variance (ANOVA) ( $n=12$ ) were conducted to determine if significant differences existed in kinematic measures (V, BW) for the three phases (Butterfly Drop, Left Leg Recovery, Right Leg Recovery) of the Butterfly Drop to Recovery movement. Findings suggested that all twelve of the twelve analyses had no significant difference between baselines.

The series of within-subject Repeated Measures Analysis of Variance (ANOVA) ( $n=12$ ) were conducted to determine if significant differences existed in kinematic measures (V) for the four phases (Butterfly Drop, Lateral Butterfly Slide, Left Leg Recovery, Right Leg Recovery) of the Lateral Butterfly Slide to Recovery movement. Findings suggested that eleven of the twelve analyses had no significant difference between baselines. Only one of the twelve analyses revealed significant differences, specifically: Butterfly Drop Velocity for AN-AM-AN, the first baseline ( $M=2.13$ ,  $SD=0.12$ ) was significantly ( $p<0.003$ ) higher than the second baseline ( $M=1.88$ ,  $SD=0.17$ ).

In summary, of the kinematic measures on the two goaltender-specific movement patterns (Butterfly Drop to Recovery, Lateral Butterfly Slide to Recovery) between the

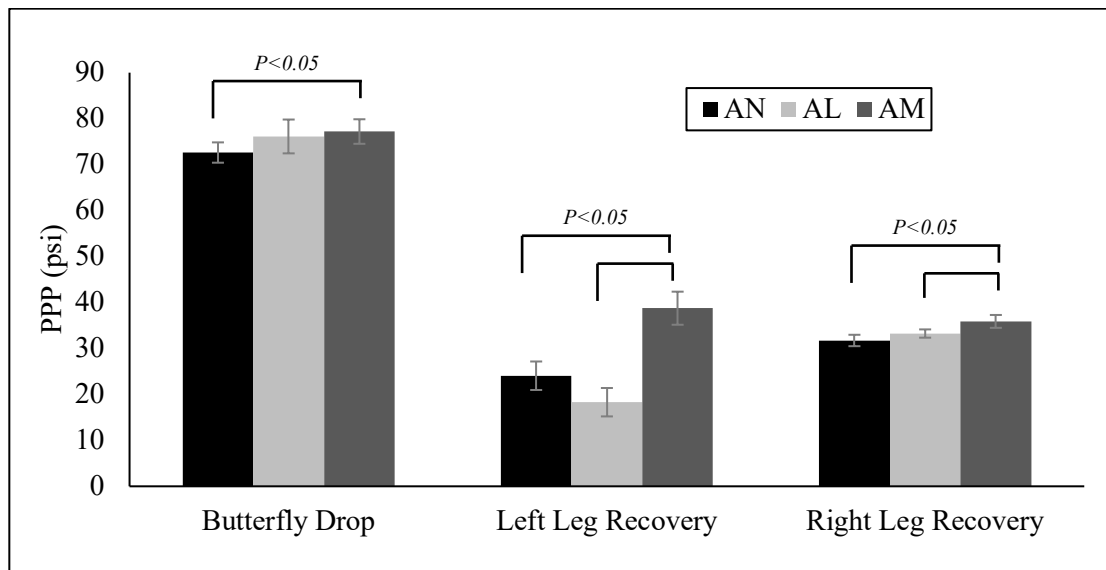
baselines in the, A-B-A study design (baseline-intervention-baseline), a total of twenty-three of twenty-four analyses showed consistency /repeatability of technique.

#### 4.3 Alignment Neutral vs. Alignment Lateral vs. Alignment Medial

The following section provides the kinetic and kinematic results of the AN, AL and AM blade alignment interventions to address research question #3: is there a significant effect of skate blade alignment in kinetic and kinematic measures for two goaltender-specific movement patterns (Butterfly Drop to Recovery, Lateral Butterfly Slide to Recovery)?

##### 4.3.1 Kinetic Analyses Across AN, AL and AM Alignment Interventions

Kinetic measures for the Butterfly Drop to Recovery (Mean  $\pm$  SD) across the three phases (Butterfly Drop, Left Leg Recovery, Right Leg Recovery) of the movement are illustrated in *Figure 15*.



*Figure 15.* Kinetic Results Across AN-AL-AM Alignments for all phases of the Butterfly

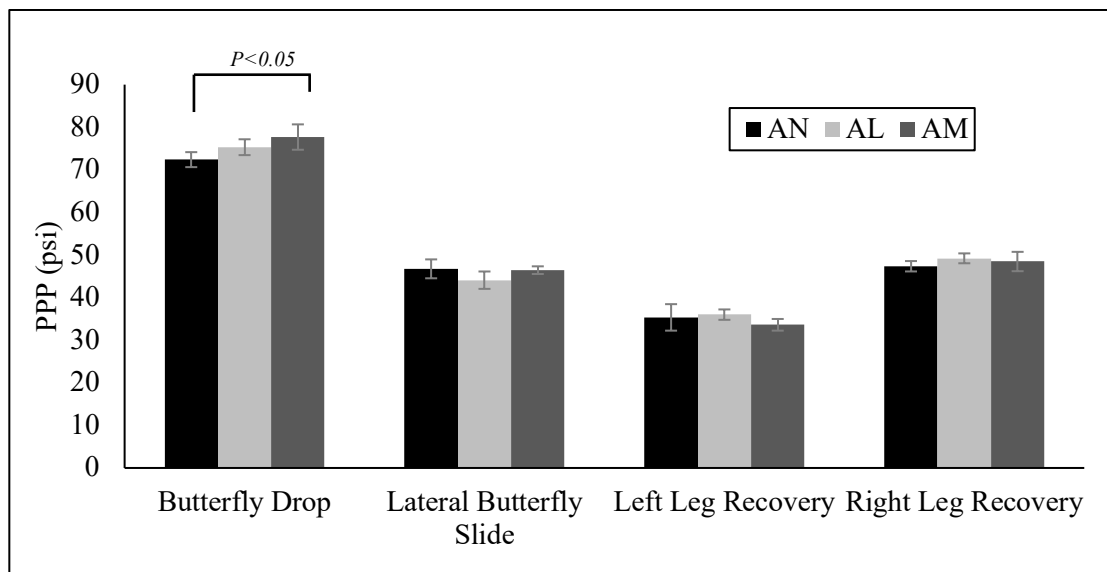


Drop to Recovery. Note: Error bars represent between trial standard deviations. TPP measures have been omitted as no significant differences were revealed across all phases.

The series of within-subject Repeated Measures Analysis of Variance (ANOVA) ( $n = 5$ ) revealed a statistically significant difference across alignment interventions and Butterfly Drop PPP,  $F(2,8) = 5.70$ ,  $p = 0.03$ , partial  $\eta^2 = 0.59$ . A pairwise comparison using a Bonferroni post hoc test revealed Butterfly Drop PPP on AM ( $M = 77.19$ ,  $SD = 2.67$ ) was significantly ( $p < 0.02$ ) higher than on AN ( $M = 72.62$ ,  $SD = 2.21$ ). Therefore, a greater amount of pressure (psi) was exerted in the AM alignment compared to the AN alignment during the Butterfly Drop phase. Results also revealed a statistically significant difference across alignment interventions and Left Leg Recovery PPP,  $F(2,8) = 41.16$ ,  $p = 0.00$ , partial  $\eta^2 = 0.91$ . A pairwise comparison using a Bonferroni post hoc test revealed Left Leg Recovery PPP on AM ( $M = 38.75$ ,  $SD = 3.60$ ) was significantly ( $p < 0.006$ ) higher than on AL ( $M = 18.30$ ,  $SD = 3.09$ ) and significantly ( $p < 0.005$ ) higher than on AN ( $M = 24.06$ ,  $SD = 3.10$ ). Therefore, a greater amount of pressure (psi) was exerted on the AM alignment compared to the AN and AL alignment during the Left Leg Recovery phase. A statistically significant difference was also revealed across alignment interventions and Right Leg Recovery PPP,  $F(2,8) = 15.90$ ,  $p = 0.02$ , partial  $\eta^2 = 0.80$ . A pairwise comparison using a Bonferroni post hoc test revealed Right Leg Recovery PPP on AM ( $M = 35.88$ ,  $SD = 1.40$ ) was significantly ( $p < 0.021$ ) higher than on AL ( $M = 33.24$ ,  $SD = 0.90$ ) and significantly ( $p < 0.031$ ) higher than on AN ( $M = 31.73$ ,  $SD = 1.24$ ). Therefore, a greater amount of pressure (psi) was exerted on the AM alignment compared

to the AN and AL alignment during the Right Leg Recovery phase. Results revealed no significant difference in TPP measures across the three blade alignment interventions (AN, AL, AM) for all three phases (Butterfly Drop, Left Leg Recovery, Right Leg Recovery) of the Butterfly Drop to Recovery movement.

Kinetic measures for the Lateral Butterfly Slide to Recovery (Mean  $\pm$  SD) across the four phases (Butterfly Drop, Lateral Butterfly Slide, Left Leg Recovery, Right Leg Recovery) of the movement are illustrated in *Figure 16*.



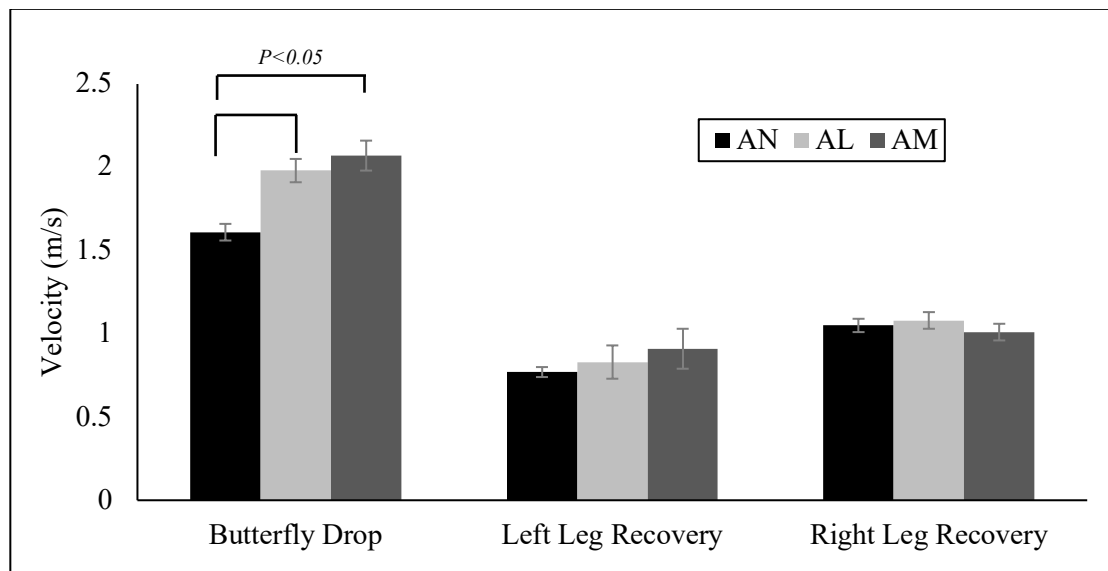
*Figure 16.* Summary of Kinetic Results Across AN-AL-AM blade alignments for all phases of the Lateral Butterfly Slide to Recovery. *Note:* Error bars represent between trial standard deviations. TPP measures have been omitted as no significant differences were revealed across all phases.

The series of within-subject Repeated Measures Analysis of Variance (ANOVA) ( $n = 7$ ) revealed a statistically significant difference across alignment interventions and Butterfly Drop PPP,  $F(2,8) = 28.68$ ,  $p = 0.00$ , partial  $\eta^2 = 0.88$ . A pairwise comparison using a Bonferroni post hoc test revealed Butterfly Drop PPP on AM ( $M = 77.69$ ,  $SD = 2.98$ ) was

significantly ( $p<0.014$ ) higher than on AN ( $M=72.38$  ,  $SD =1.76$ ), and Butterfly Drop PPP on AL ( $M= 75.31$ ,  $SD = 1.86$ ) was significantly ( $p<0.007$ ) higher than on AN ( $M=72.38$  ,  $SD =1.76$ ). Therefore, a greater amount of pressure (psi) was exerted on the AM and AL alignment compared to the AN alignment during the Butterfly Drop phase. Results revealed no significant difference in TPP measures across the three blade alignment interventions (AN, AL, AM) for all four phases (Butterfly Drop, Lateral Butterfly Slide, Left Leg Recovery, Right Leg Recovery) of the Lateral Butterfly Slide to Recovery movement.

#### 4.3.2 Kinematic Analyses Across AN, AL and AM Alignment Interventions

Kinematic measures for the Butterfly Drop to Recovery (Mean  $\pm$  SD) across the three phases (Butterfly Drop, Left Leg Recovery, Right Leg Recovery) of the movement are illustrated in *Figure 17*.

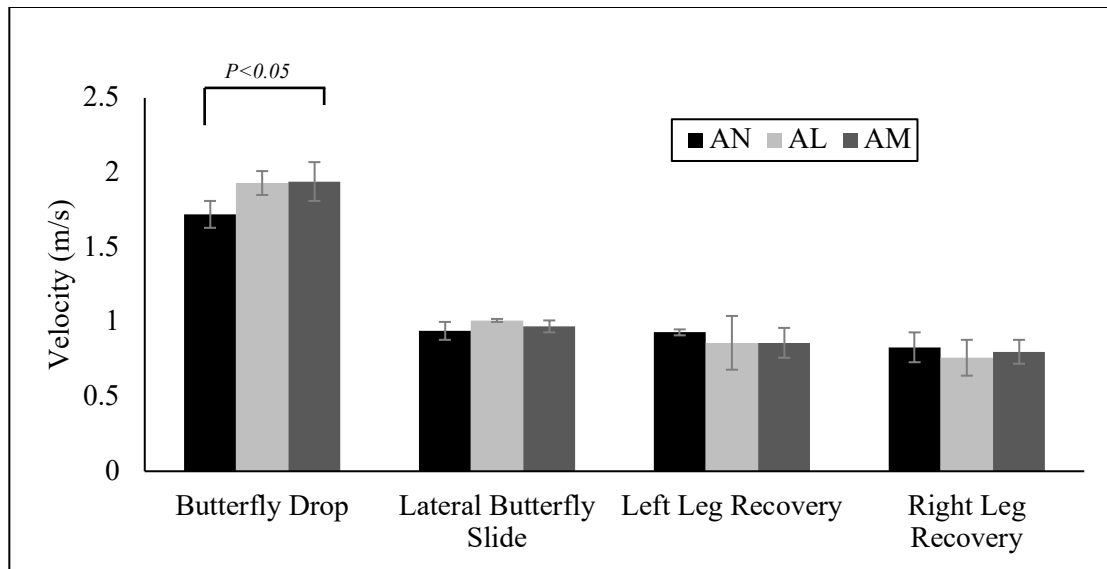


*Figure 17.* Summary of Kinematic Results Across AN-AL-AM blade alignments for all phases of the Butterfly Drop to Recovery. *Note:* Error bars represent between trial

standard deviations. BW measures have been omitted as no significant differences were revealed across all phases.

The series of within-subject Repeated Measures Analysis of Variance (ANOVA) ( $n=4$ ) revealed a statistically significant difference across alignment interventions and Butterfly Drop Velocity (BDV)  $F(2,8) = 59.93$ ,  $p = 0.0$ , partial  $\eta^2 = 0.94$ . A pairwise comparison using a Bonferroni post hoc test revealed BDV on AM ( $M=2.07$ ,  $SD=0.09$ ) was significantly ( $p<0.004$ ) higher than on AN ( $M=1.61$ ,  $SD=0.05$ ), and BDV on AL ( $M=1.98$ ,  $SD=0.07$ ) was significantly ( $p<0.002$ ) higher than on AN ( $M=1.61$ ,  $SD=0.05$ ). Therefore, the Butterfly Drop phase was executed faster on AM and on AL compared to on AN. Results revealed no significant differences across the three blade alignment interventions in Left Leg Recovery Velocity (LBRV), Right Leg Recovery Velocity (RBRV), and Butterfly Width (BW).

Kinematic measures for the Lateral Butterfly Slide to Recovery (Mean  $\pm$  SD) across the four phases (Butterfly Drop, Lateral Butterfly Slide, Left Leg Recovery, Right Leg Recovery) of the movement are illustrated in *Figure 18*.



*Figure 18.* Summary of Kinematic Results Across AN-AL-AM blade alignments for all phases of the Lateral Butterfly Slide to Recovery. *Note:* Error bars represent between trial standard deviations. BW measures have been omitted as no significant differences were revealed across all phases.

The series of within-subject Repeated Measures Analysis of Variance (ANOVA) ( $n = 4$ ) revealed a statistically significant difference across alignment interventions and Butterfly Drop Velocity (BDV)  $F(2,8) = 9.50$ ,  $p = 0.008$ , partial  $\eta^2 = 0.70$ . A pairwise comparison using a Bonferroni post hoc test revealed BDV on AM ( $M = 1.94$ ,  $SD = 0.13$ ) was significantly ( $p < 0.04$ ) higher than on AN ( $M = 1.72$ ,  $SD = 0.09$ ). Therefore, the Butterfly Drop phase was executed faster on AM compared to on AN. Results revealed no significant differences across the three blade alignment interventions in Lateral Butterfly Slide Velocity, Left Leg Recovery Velocity and Right Leg Recovery Velocity.

#### 4.4 Borg Scale Data

Following each set of five trials, the participant self-reported a rating of perceived exertion (RPE) scale of 6-20 (Borg, 1998). Borg Scale data (see *Table 3*) ranged from scores of six to eleven.

Table 3

*RPE Scores Across Data Collection*

Alignment Condition		Baseline	Intervention	Baseline
Day 1	Butterfly Drop to Recovery Trials	6	8	10
	Lateral Butterfly Slide to Recovery Trials	7	9	10
Day 2	Butterfly Drop to Recovery Trials	6	7	10
	Lateral Butterfly Slide to Recovery Trials	8	9	11
Day 3	Butterfly Drop to Recovery Trials	7	9	8
	Lateral Butterfly Slide to Recovery Trials	9	10	9

The maximum RPE score recorded was eleven indicating ‘light exertion’. The low scores of RPE across data collection provided the researcher with confidence that exertion did not influence technical execution of the Butterfly Drop to Recovery and Lateral Butterfly Slide to Recovery.

## CHAPTER V: DISCUSSION

Traditionally, the goaltender skate design included a cowling, a plastic form wrapped around the lower portion of the boot to provide protection and act as a blade holder to secure the blade runner. Current day material properties of the skate boot include synthetic materials, carbon fibers, and resins with reinforced toecaps to improve protection, structure, and durability (U.S. Patent No. US15087213, 2015; U.S. Patent No. 20170080323A1, 2015) and have eliminated the need for the additional protection previously provided by the cowling. Therefore, the cowling has been considered redundant and has been replaced by goaltender blade holders that resemble the design of a player's blade holder. The new goaltender blade holders have provided an opportunity to adjust blade alignment and investigate the effect of blade alignment on select kinetic and kinematic variables during the execution of two different goaltender-specific movement patterns. For the purpose of the study, two goaltender-specific movement patterns (Butterfly Drop to Recovery and the Lateral Butterfly Slide to Recovery) were analyzed. Blade alignment conditions were defined by the blade holder (Bauer Vertexx cowling, True Hockey blade holders) and the positioning of the blade holder [alignment neutral cowling (ANC), alignment neutral (AN), alignment lateral (AL), and alignment medial (AM)] in the frontal plane in regard to the centre of the boot. For the purpose of comparing holder types, the cowling that facilitates a neutral alignment (ANC) was compared to the neutral alignment (AN) condition in the True Hockey blade holders. The True Hockey blade holders were further retrofit with a slotted design to allowed the blade to be moved in the medal and lateral directions for the AN, AL, AM blade alignments.

Research question 1 addressed whether there was a significant difference in kinetic [Peak Plantar Pressure (PPP), Time to Peak Plantar Pressure (TPP)] and kinematic [Velocity (V), Butterfly Width (BW)] measures between two neutral alignments (ANC, AN) facilitated by different holder types for two goaltender-specific movement patterns (Butterfly Drop to Recovery, Lateral Butterfly Slide to Recovery). It was anticipated that since both holders positioned the blade in a neutral position, there would be no significant difference in kinetic or kinematic measures and in fact, results revealed no significant differences in nineteen of the twenty outcome measures (kinetic: PPP, TPP; kinematic BDV, BW, LBSV, LLRV, RLRV). The non-significant outcomes provide evidence to suggest that execution of technique in both blade holders (ANC and AN) does not differ. Neutral means aligned longitudinally from the second metatarsal head and second digit, to the center of the heel (Humble, 2003). The isolated difference (1 out of 20 variables) was the Butterfly Drop PPP on the Butterfly Drop phase of the Lateral Butterfly slide, where there was a mean difference of 3.79 psi. This difference was negligible as it was not enough to elicit a significant difference between ANC and AN in the kinematic measure (BDV) for the same phase. Results provided evidence to support the hypothesis that AN=ANC. Therefore AN was used as the baseline alignment for further collection days.

Research question 2 addressed whether technique across two different goaltender-specific movement patterns was consistent/repeatable for each phase of movement when analyzing kinetic [Peak Plantar Pressure (PPP), Time to Peak Plantar Pressure (TPP)] and kinematic [Velocity (V), Butterfly Width (BW)] measures between the baseline conditions in the A-B-A, baseline-intervention-baseline study design. An A-B-A design



allowed for a comparison of A to A, as a measure of consistency and repeatability of kinetic and kinematic variables collected across trials using the same technique. Thirty-five of the forty-two kinetic analyses and twenty-three of the twenty-four kinematic analyses revealed non-significant differences between A and A, meaning that the technique used by the participant was rather consistent with minimal variation in execution. The 10,000-hour rule suggests that 10,000 hours of practice is required to fully develop and automate technique (Ericsson et al.,1993). For the purpose of this study, the subject recruited was an experienced goaltender with twenty years of experience in executing goaltender-specific movement patterns at a high level of competition. It could be assumed that the subject had acquired a level of automation in executing the two of goaltender-specific movement patterns, which may translate to limited variability between and across trials.

That said, seven of the forty-two analyses revealed significant differences between select kinetic baseline measures, meaning these seven measures revealed greater variability when executing the same phase of the movement pattern. Possible explanations for the differences between baselines across these seven measures may be related to the insoles only collecting plantar pressure data on the footbed of the skate and not on the medial or lateral sides of the boot. Therefore, a small adjustment of the foot within the skate between trials may have led to a redistribution of plantar pressure from the footbed to the medial or lateral edges of the skate boot, unable to be measured by the instrumentation. However, the associated kinematic measure for those seven phases of movement did not reveal significantly different baselines, suggesting the kinetic differences between baselines had a negligible effect on kinematic execution of

technique. Butterfly Drop Velocity for AN-AM-AN during the Lateral Butterfly Slide to Recovery movement was the only kinematic measure revealing differences between baselines; the first baseline was found to be 0.25m/s faster than the second baseline. In summary, the single-subject design limited variability, in this case, the consistency of technique, without influences caused by different styles of play, or foot types (normal, pronated, supinated) across multiple subjects.

As anticipated, the two neutral alignment conditions (ANC, AN) were the same, and the execution of technique across data collection was consistent/repeatable. Results of these two research questions provided the researcher with the confidence to use AN as the baseline condition for the remainder of data collection, and to suggest that there was limited effect of learning or exertion influencing the data, providing a foundation to explore differences across blade alignment interventions.

Research question #3 addressed whether there was a significant difference in kinetic [Peak Plantar Pressure (PPP), Time to Peak Plantar Pressure (TPP)] and kinematic [Velocity (V), Butterfly Width (BW)] measures across the three blade alignments interventions (AN, AL, AM) for two goaltender-specific movement patterns.

Kinetic PPP measures for all three phases of the Butterfly Drop to Recovery movement were consistently the highest when performing on the AM blade alignment, or in other words, the highest amount of peak pressure exerted on the insoles was revealed on the AM blade alignment. A possible explanation could be that these phases of the movement are initiated from the medial edge of the skate blades driving into the ice, with plantar pressure being predominantly driven through the athlete's first metatarsal. Therefore, positioning the blade under the athlete's COP may have contributed to AM

having the highest PPP, as force was exerted directly through the blade and into the ice rather than on an angle to the blade. Alternatively, high PPP on the AM condition may be due to the increased attack angle, defined as the angle at which the blade can remain in contact with the ice before the medial edge of the skate boot contacts the ice causing 'slip-out', allowing the goaltender to generate force at a smaller angle with the ice compared to AN and AL. Consistent with the first phase of the Butterfly Drop to Recovery movement, PPP for both recovery phases (LLRV, RLRV) was highest on the AM blade alignment. A possible explanation for this could be that the Left and Right Leg Recoveries are unilateral techniques also initiated from the medial edge of the skate blades driving into the ice with plantar pressure being predominantly driven through the athlete's first metatarsal similar to the Butterfly Drop phase. Kinetic Butterfly Drop PPP for the Lateral Butterfly Slide to Recovery movement was highest on AM, and significantly higher on AM compared to AN, consistent with the Butterfly Drop to Recovery movement, and significantly higher with AL compared to AN. The similarity of these results was anticipated as the Butterfly Drop phase for the two movements is identical technique. In contrast to the recovery phases of the Butterfly Drop to Recovery movement, PPP for both recovery phases (LLRV, RLRV) of the Lateral Butterfly Slide to Recovery movement were not significantly affected by blade alignment. Technique of the lateral butterfly slide recoveries (LLRV, RLRV) is significantly different than the butterfly recoveries of the Butterfly Drop to Recovery. Butterfly drop recoveries are characterized by forces directed downwards into the ice in order to propel the athlete vertically to their feet for both legs whereas lateral butterfly slide recoveries involve different technique. The RLRV technique of the Lateral Butterfly Slide movement is

initiated by the goaltender driving the right skate into the ice in order to match the lateral slide momentum generated by the lateral push, while simultaneously directing force into the ice in order to propel the athlete vertically to their feet. In order to stop lateral momentum, the subject had to apply an impulse equal to the momentum in the opposite direction. The LLRV is characterized by a weight shift from the right leg to the left leg, and as weight did not change throughout collection, this may explain why no significant difference was found across alignments for the LLRV.

Kinematic Butterfly Drop Velocity (BDV) for the Butterfly Drop to Recovery movement was significantly highest on AM compared to AN, and BDV on AL was significantly higher than on AN. Force is predominantly driven through the athlete's first metatarsal in order to generate internal rotation of the legs in order for the knees to make contact with the ice, and since no time is wasted shifting force to the medial edge in the AM blade alignment as it aligns the blade holder and runner on the medial edge of the skate, this may have potentially facilitated an increased velocity while performing the Butterfly Drop phase. Another potential reason for the fastest Butterfly Drop phase being executed on AM may be due to the increased attack angle associated with the AM blade alignment. This increased attack angle may allow the goaltender to generate force for a longer period of time as the blade will remain in contact with the ice for longer. Increasing the time of application of the force may be the reason why a faster velocity from on the feet to the butterfly positioning on the ice occurred. Kinematic Butterfly Drop Velocity (BDV) for the Lateral Butterfly Slide to Recovery movement was significantly highest when performed on the AM blade alignment, consistent with the

Butterfly Drop to Recovery movement. The consistency of these results was anticipated as the Butterfly Drop phase for the two movements involves identical technique.

Kinematic results of the current study provide evidence of the contribution of equipment to BDV. This add to the research by Frayne and Dickey (2017), which revealed higher Peak Butterfly Drop Velocity with the flex-tight leg pad channel. The current study expanded on the performance measures from Frayne and Dickey (2017). including Left Leg Recovery Velocity, Right Leg Recovery Velocity, as well as the analysis of the Lateral Butterfly Slide to Recovery movement. In addition, a comprehensive analysis of kinetic measures was unique to this study.

Results provided empirical evidence to support a performance effect related to medial-lateral skate blade alignment on save techniques executed by goaltenders. In summary, this study adds to the small body of research that focuses on the contribution of equipment to ice hockey goaltender performance and initiates potential avenues of further research into the biomechanical effects of skate blade alignment on other goaltending specific movements, other positions in hockey, along with other sliding and gliding sports.

## **5.1 Practical Applications**

Outcomes of the study have significant practical applications to the goaltender, hockey equipment manufacturers, and equipment managers. The main objective of the goaltender is to prevent the opposing team from scoring, facilitated by moving into position as quickly and as precisely as possible in order to block shots and make saves. The potential to enhance a goaltender's save-positioning ability and prevent the puck from entering the net increases the possibility of winning a game. Findings suggested that

manipulating blade alignment improved BDV, and therefore, altering blade alignment has the potential to impact the outcome of a hockey goaltender's save abilities. In order to understand what these changes really mean in the context of a hockey game, imagine the following scenario: based on the mean vertical displacement from ready stance to butterfly positioning for our subject (0.49m), and mean shot velocities by college level players (30.6m/s) (Wu et al., 2003), our subject could achieve the butterfly positioning in time for the puck to make contact with them for a shot from: AN - 9.27m (30.41 feet); AL - 7.56m (24.80 feet); AM - 7.22 m (23.69 feet). Therefore, in a scenario where our subject is using the AM blade alignment, there is potential to achieve the butterfly positioning for a shot from 2.05m (6.72 feet) closer compared to when in the AN blade alignment. The ability to execute the butterfly position completely with the shooter 2.05m (6.72 feet) closer is a major advantage in a hockey game as it provides the goaltender the ability to get into position for a larger percentage of total shot scenarios, especially considering the offensive zone of the rink is only 19.51m (64 feet) long (USA Hockey, 2018a).

The results of this study provide evidence that blade alignment has the potential to positively contribute to the execution of goaltender-specific techniques, and therefore skate manufacturers need to consider blade alignment when developing future goaltender skates. Within the current hockey equipment industry, blade alignment customization is available to player skates, however the practice is typically reserved for high level players. Expertise has governed this practice, and no instrumentation provides information for ideal blade alignment per individual. When a goaltender buys a skate, the concept of blade alignment was traditionally not an option for consideration, and

therefore, there was no expertise to inform this practice. The ability to manipulate goaltender skate blade alignment has not been an option until 2015 (U.S. Patent No. US15087213, 2015; U.S. Patent No. 20170080323A1, 2015). Although manufacturers do not typically customize skates for the masses, they may want to consider standardizing an alignment that suits the greatest number of goaltenders or develop a slotted blade system that allows goaltenders to manipulate their blade alignment to suit their own preference. Traditionally at the elite level, manufacturers provide skates and holders loose, meaning that they are not riveted and it is the equipment managers responsibility to mount the blade holder specific to their goaltender's preferred blade alignment. This study may not inform what blade alignment is best suited to each individual goaltender, however it does inform equipment managers that blade alignment has the potential to significantly contribute to the execution of goaltender-specific movement patterns inviting them to investigate and experiment with their goaltenders with different blade alignments other than the stock neutral alignment. Specific to our subject, results inform equipment managers that the AM blade alignment facilitates faster butterfly positioning.

## **5.2 Limitations**

Limitations of this study include the single-subject design and the analysis of only two goaltender-specific movements. The single-subject design was implemented to ensure consistency/repeatability of techniques, while avoiding possible co-variants with a multiple subject design. The design limits generalizability of findings as the results do not determine what alignment is best suited to any other goaltenders other than the subject, however, it provides empirical evidence to support the effect of manipulating blade

alignment on a goaltender skate on the execution of goaltender-specific movement patterns.

The second limitation was the analyses of only two goaltender-specific movement patterns (Butterfly Drop to Recovery, Lateral Butterfly Slide to Recovery). The goaltending position is an extremely dynamic position with many different movement patterns, including but not limited to combinations of anterior/posterior and medial/lateral movements when on the feet, as well as with the legs on the ice. The generalizability of the results of this study are limited to only two goaltender-specific movement patterns of many. However, the use of the combinations of the butterfly save technique (Butterfly Drop to Recovery, Lateral Butterfly Slide to Recovery) were informed by TMA analysis by Bell et al. (2008), as the butterfly save technique ( $34\pm6$ ) was identified as the most prevalent save techniques used within the capacity of an NHL game.

Another limitation of the study was the inability to control for a testing effect in the A-B-A design. A testing effect refers to the subject learning, or improving performance due to previous exposure of a condition. The A-B-A design did not account for what may have been learned by the subject in between A (baseline one) to A (baseline two) conditions. This testing effect may be a potential explanation for the inconsistency of kinetic and kinematic measures revealed between baseline conditions in research question 2. The potential of a testing effect informed the decision to recruit an elite level subject in order to minimize the learning curve from a baseline neutral condition to a baseline neutral condition due to the high level of automation in executing the two of goaltender-specific movement patterns.



Lastly, the inability to measure centre of pressure (COP) measures is a limitation of the study. Incorporation of COP, or the location of the ground reaction force, would have contributed to the strength of the kinetic results. COP measures would have provided insight on how medial-lateral skate blade alignment manipulation effected the location of the ground reaction force, which may have resulted in a stronger explanation of the kinematic findings. The in-skate pressure distribution insoles (LogR™, Orpyx® Medical Technologies Inc.) were validated against Tekscan® F-Scan™ and findings revealed that they did not significantly differ for absolute measures as well as creep and hysteresis measures (Orpyx Medical Technologies, 2017). However, the LogR™ insoles were engineered as a wearable medical technology with the purpose of detecting pressure at the points notorious for ulcer development to alert users to readjust standing posture. This study was one of the first to use the LogR™ insoles in a sport application. Since the insoles consist of only eight large sensors positioned at the bony prominences of the foot, the measures for COP are non-reliable due to the lack of sensors, and the inability to extrapolate in-sensor data of individual sensors.

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## APPENDIX A- Glossary Terms

*AL – Alignment Lateral:* the blade was shifted 0.55cm laterally from the centre of the boot

*AM – Alignment Medial:* the blade was shifted 0.55mm medially from the centre of the boot

*AN – Alignment Neutral:* centered blade alignment

*ANC – Alignment Neutral Cowling:* the cowling dictated a neutral or centred blade alignment

*ANOVA - Analysis of Variance*

*BDV - Butterfly Drop Velocity:* the velocity from the onset of movement from the ready stance until the leg pads are flush with the ice in the butterfly position

*BW – Butterfly Width:* the horizontal distance between the feet when in the butterfly position

*CAST - Calibrated Anatomical Systems Technique:* A 3-D marker set for hip joint kinematics for internal-external rotation, flexion-extension, and abduction-adduction

*COP – Centre of Pressure:* the position of the ground reaction force

*GRF – Ground Reaction Force:* the total force applied by the surface to the athlete

*LBSV – Lateral Butterfly Slide Velocity:* defined by horizontal distance (m) covered divided by time (s) from onset of lateral butterfly slide to the upper thigh marker of the right pad reaching the vertical height associated with the subject's ready stance following the right leg butterfly recovery phase

*LLRV – Left Leg Recovery Velocity:* defined by the velocity from the onset of movement of the left leg from the butterfly positioning back to the ready stance

*M - Mean*

*NHL - National Hockey League*

*PPP – Peak Plantar Pressure:* Kinetic measure of the greatest plantar pressure (psi)  
measured by an in-skate plantar pressure measurement device

*psi – Pounds per Square Inch:* Unit of pressure measurement

*RLRV – Right Leg Recovery Velocity:* defined by the velocity from the onset of  
movement of the right leg from the butterfly positioning back to the ready stance

*ROC – Radius of Contour:* the profile of the blade in the longitudinal plane

*ROH – Radius of Hollow:* the radius of the groove sharpened between the inside and  
outside edge of the width of the bottom of the blade

*ROM - Range of Motion*

*RPE - Rate of Perceived Exertion*

*SD- Standard Deviation*

*TMA – Time Motion Analysis:* used within sport to determine the frequency of specific  
movement patterns used within a game or event

*TPP – Time to Peak Plantar Pressure:* defined by the time from onset of movement to  
the peak plantar pressure

*V - Velocity*

*W:R- Work to Rest Ratio*